

# Florida Department of Transport APT and Instrumentation Workshop

Subgrade Deformation:  
The development of mechanistic-  
empirical design transfer functions  
from HVS data

H L Theyse  
Transportek CSIR



# Structure of presentation

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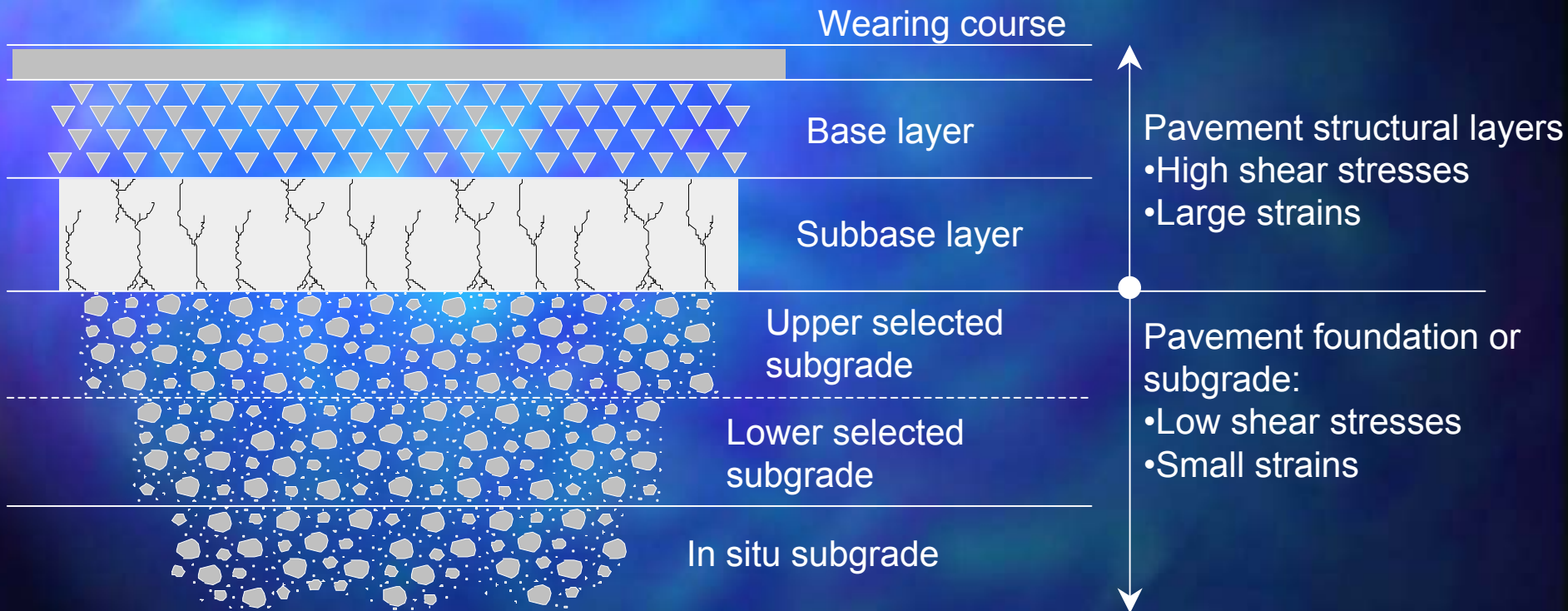
- Background
  - Subgrade definition
  - Site selection
- Analysis process
- Elastic response
- Plastic response
- Design models

# Background and analysis process

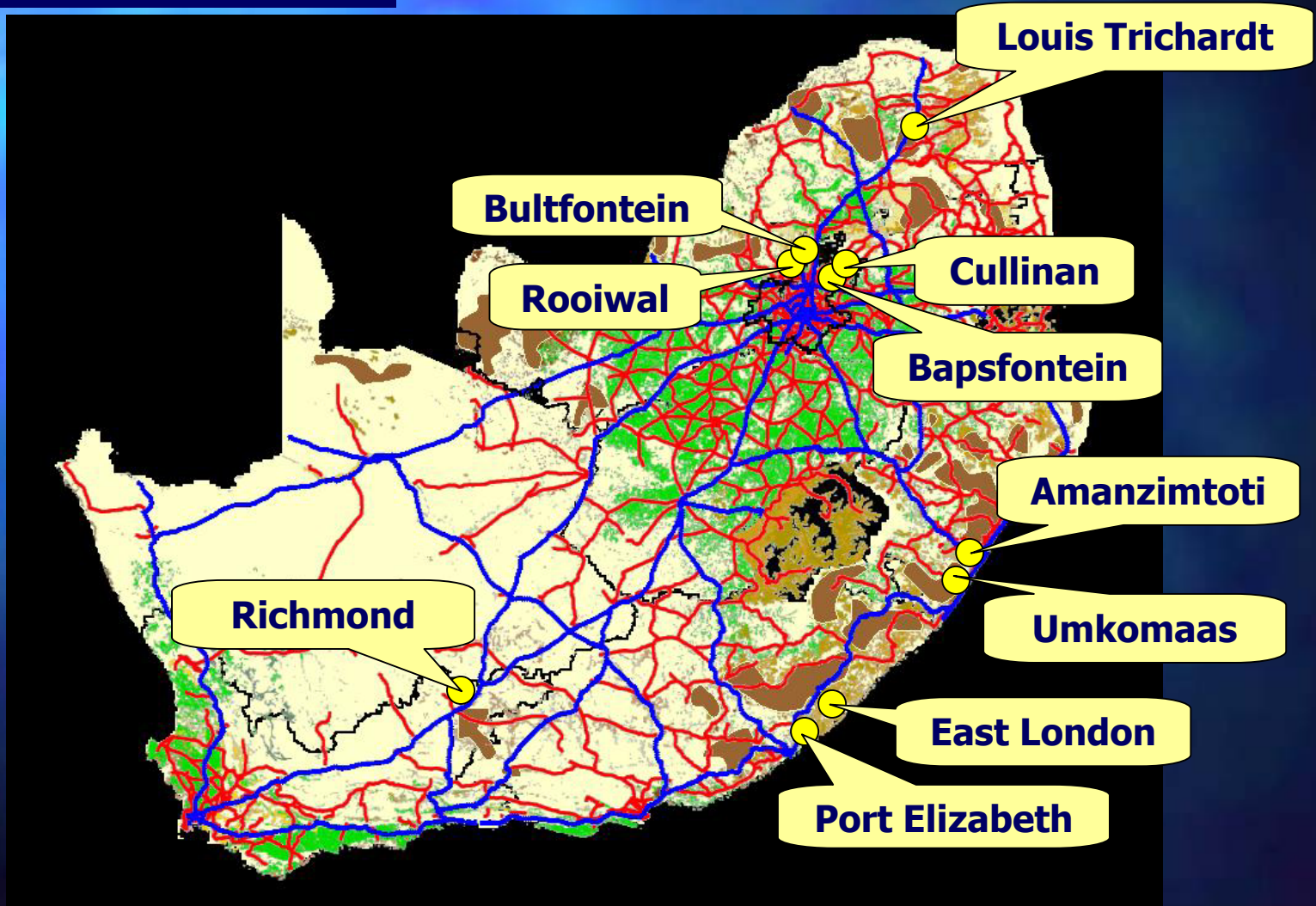
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Subgrade Deformation:  
The development of mechanistic-empirical design transfer functions from HVS data

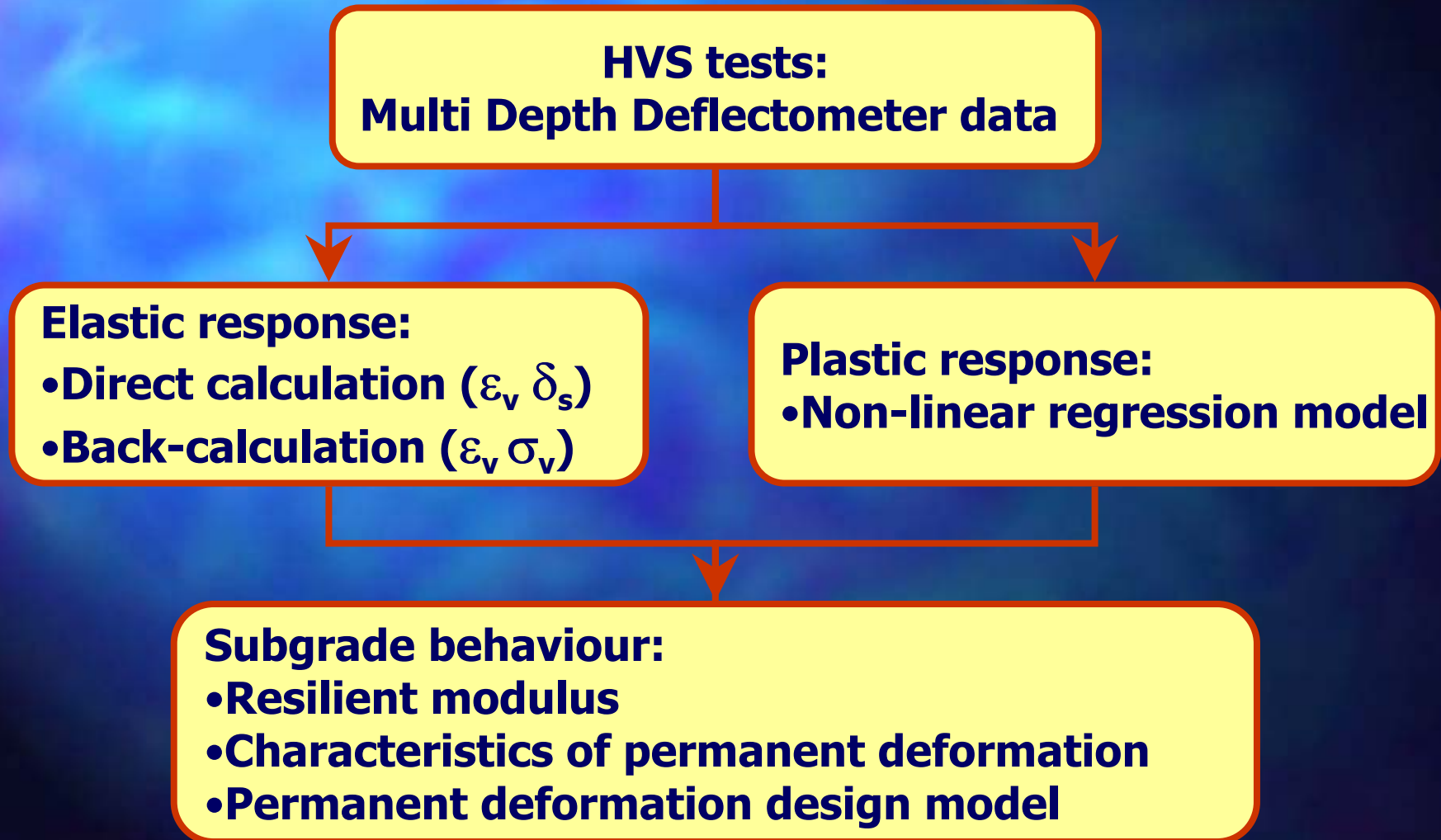
# Subgrade definition



# HVS tests used in study

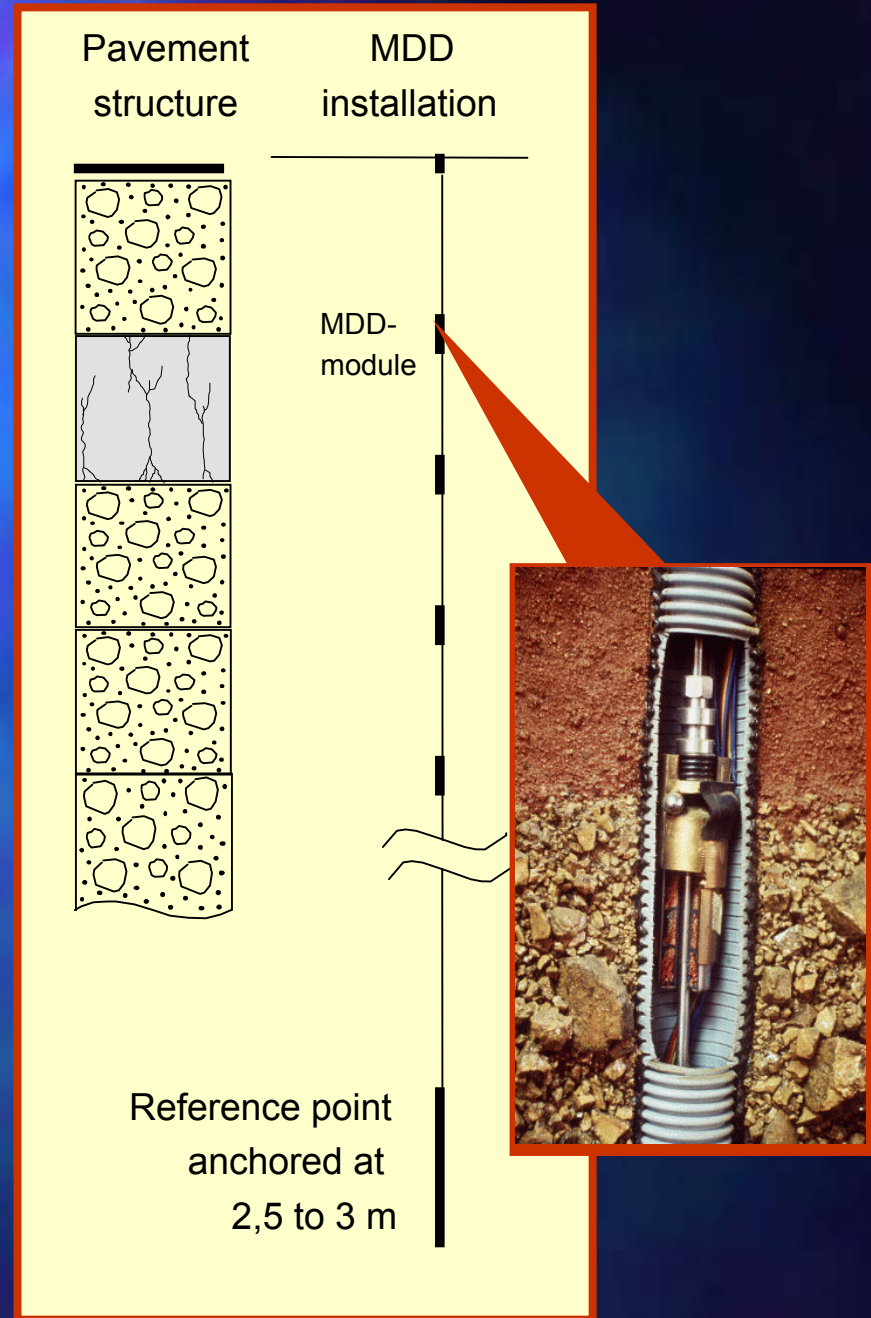


# Analysis process



# HVS testing: MDD installation

- MDD modules at layer interfaces
- Anchor at 2,5 to 3 m



# Elastic response

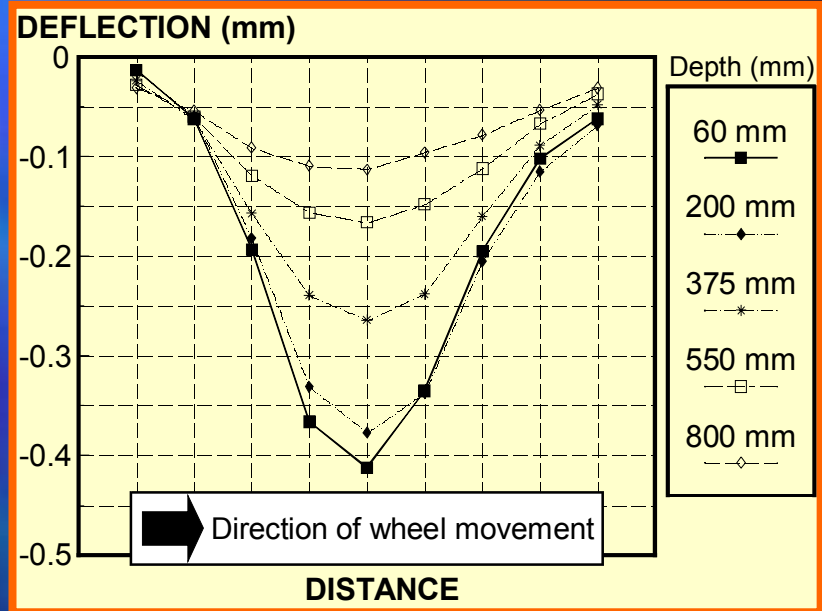
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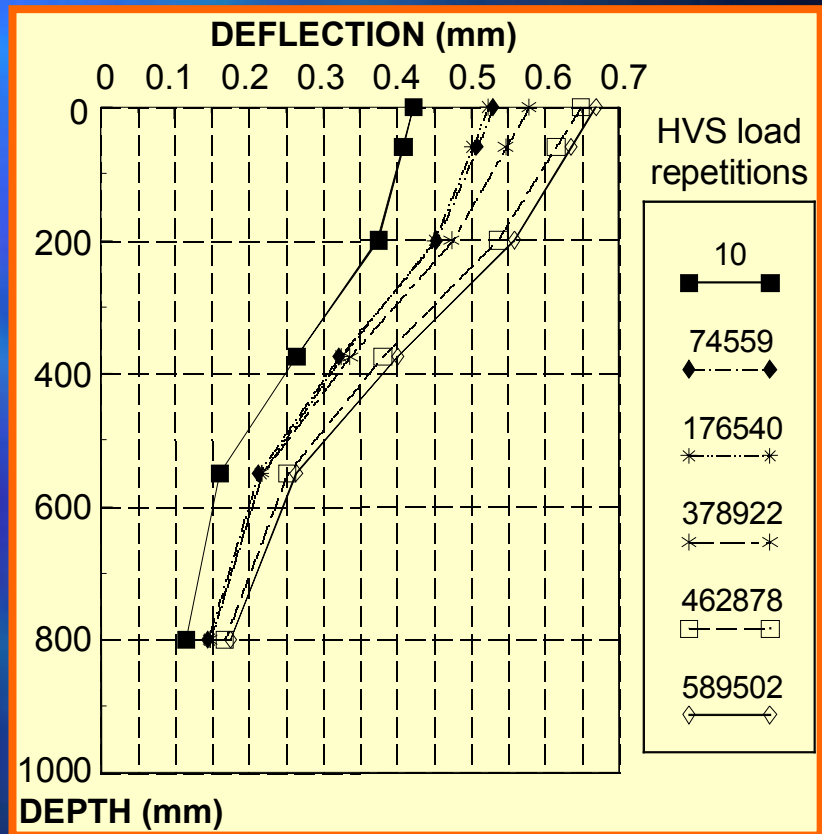
# Elastic response: Depth deflection bowls

- 256 data points on each bowl
- Peak deflections

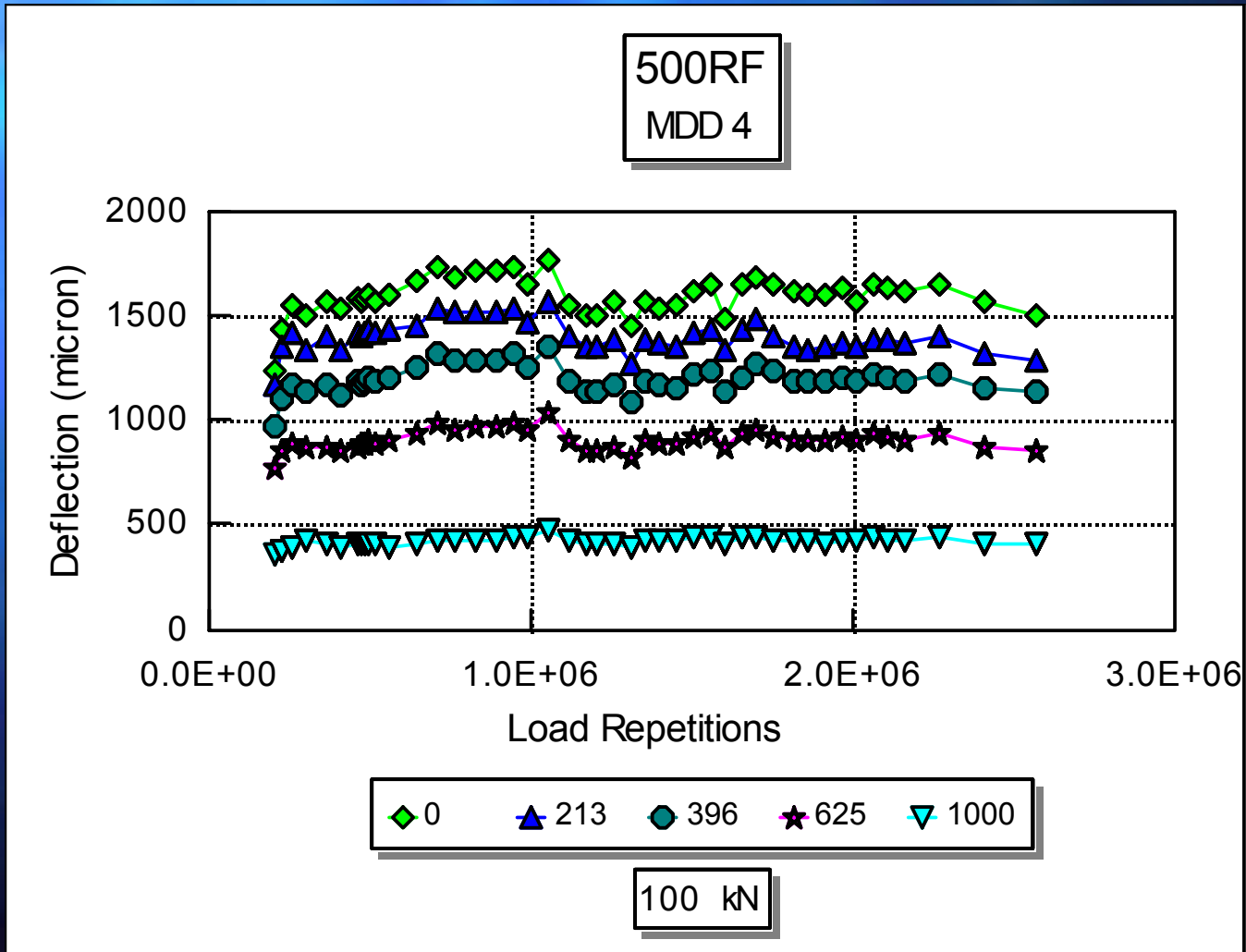


# Elastic response: Depth deflection profile

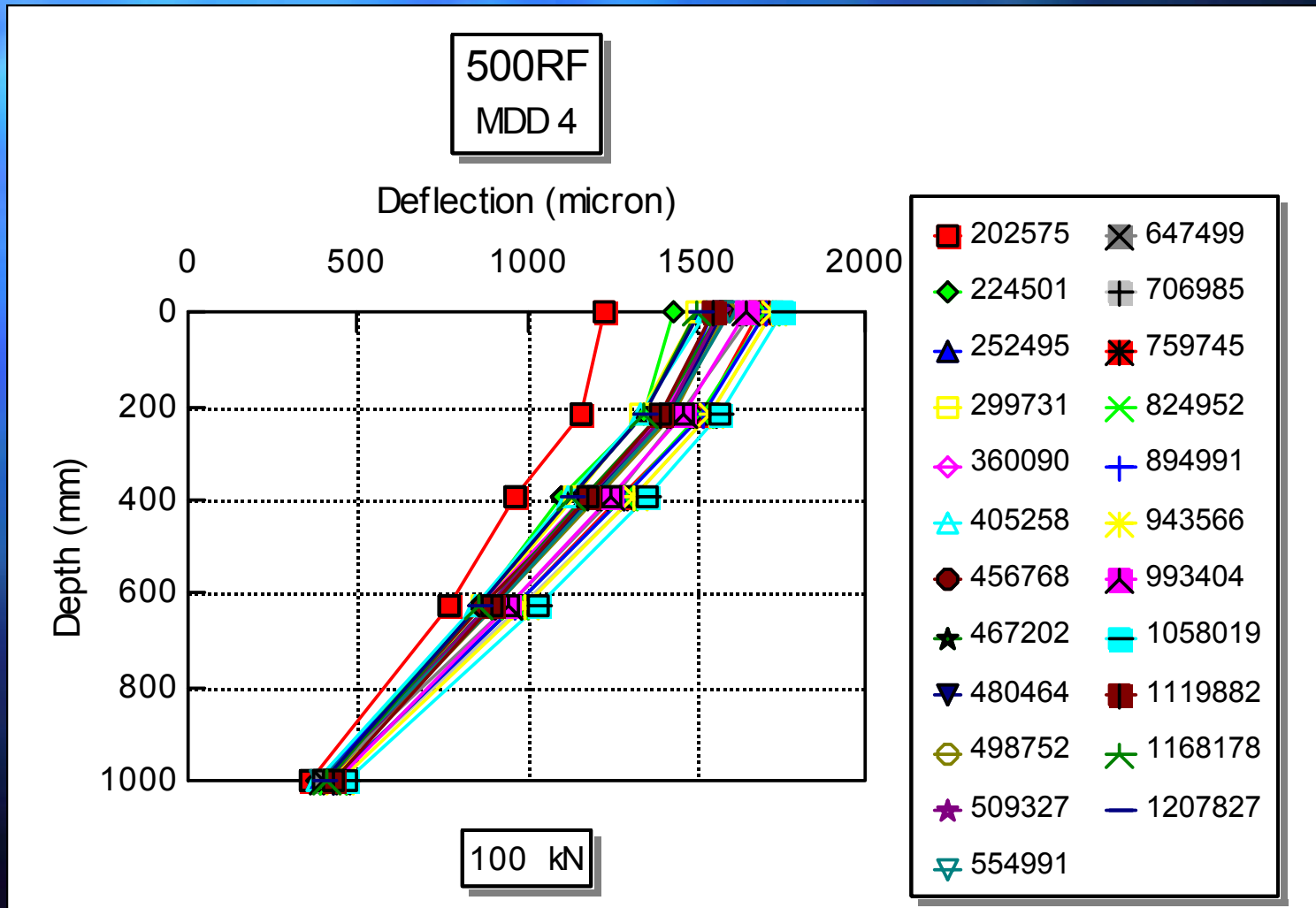
- Direct calculation
  - Average vertical strain between MDD modules
  - Elastic subgrade deflection
- Back-calculation
  - At least 2 modules in subgrade
  - Vertical stress and strain at top of subgrade



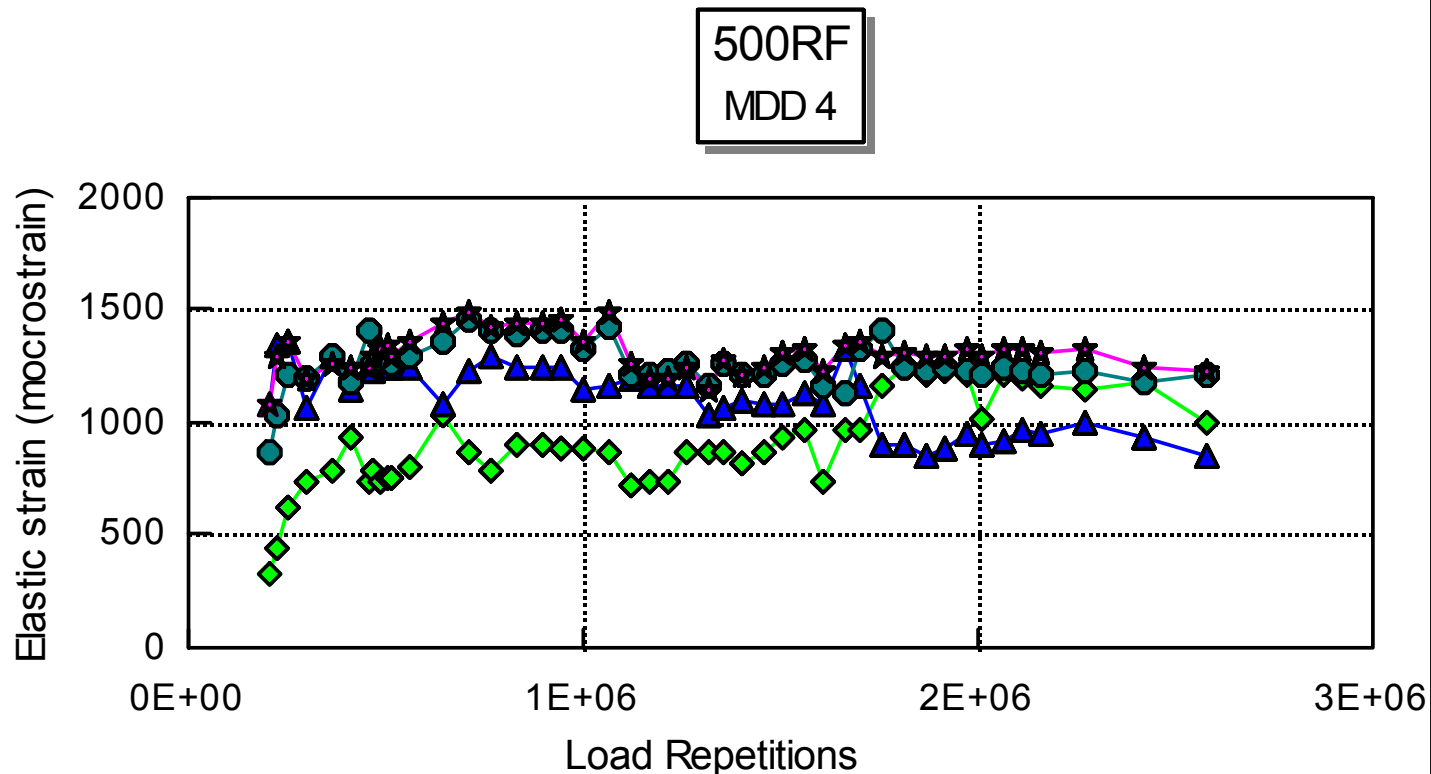
# MDD depth deflection data: Deflection history



# MDD depth deflection data: Deflection profile



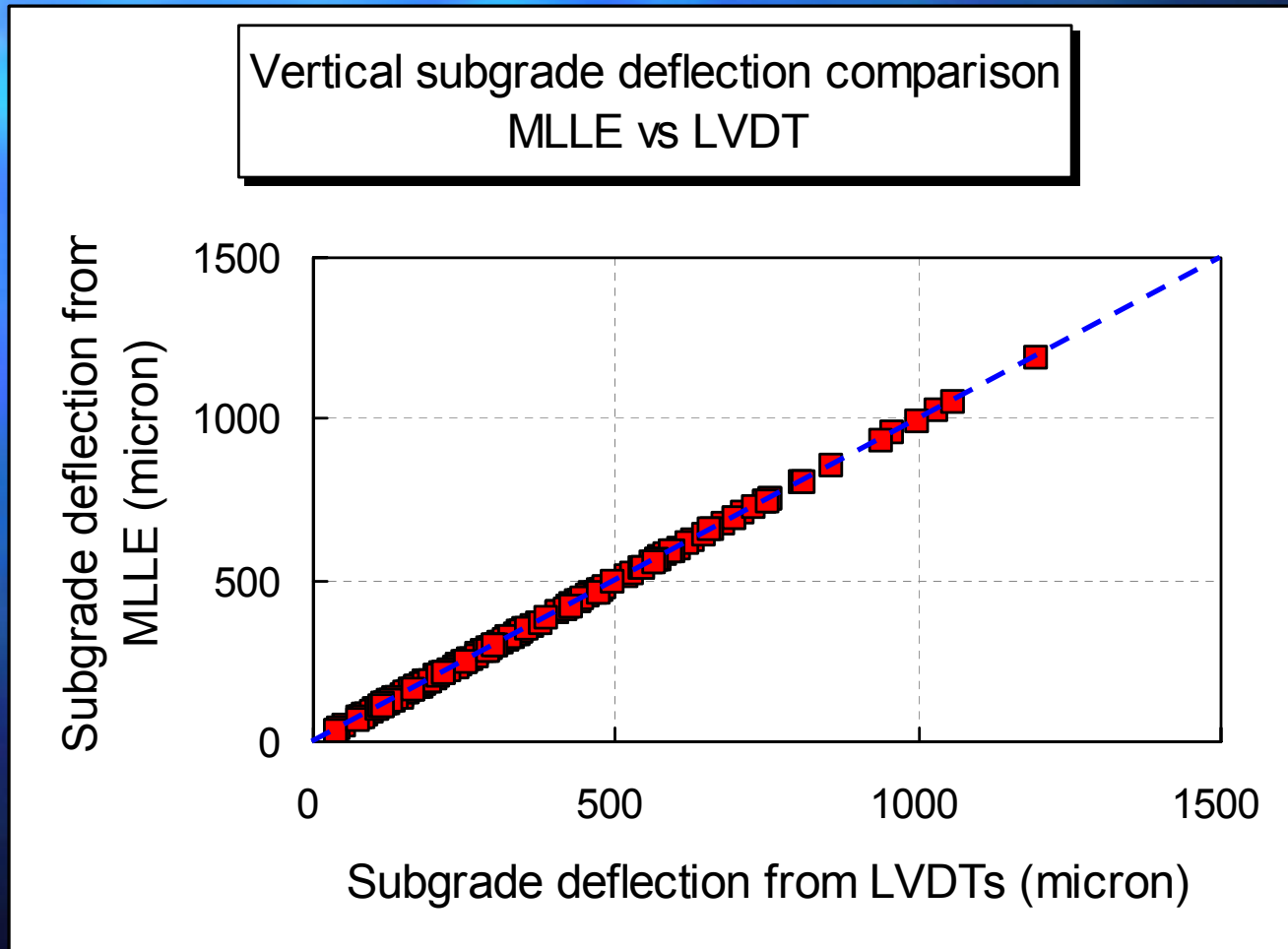
# Analysis process: Average layer elastic strain



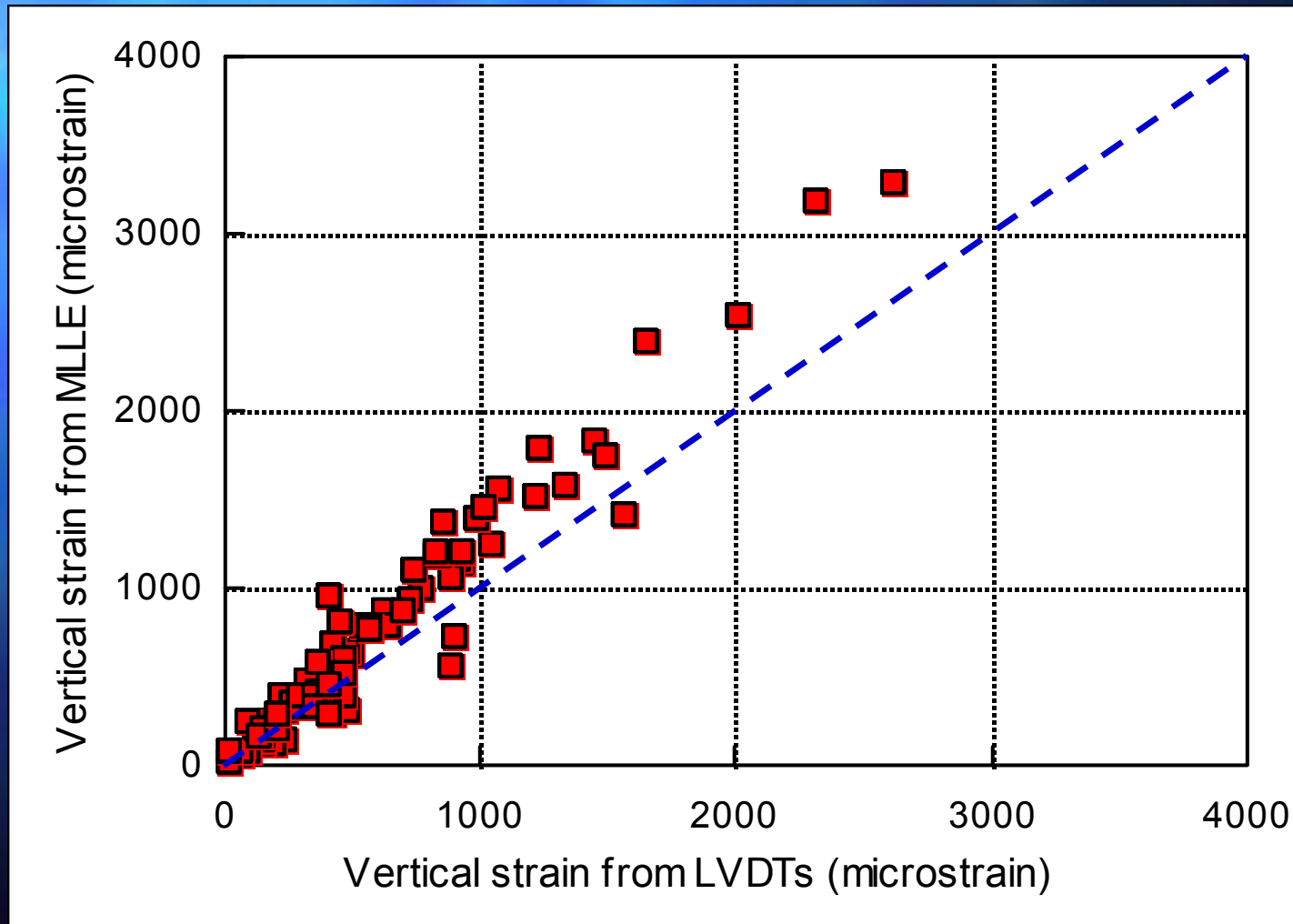
◆ 0 - 213    ▲ 213 - 396    ● 396 - 625    ★ 625 - 1000

100 kN

# Analysis process: Direct vs. back-calculation



# Analysis process: Direct vs. back-calculation



# Plastic response

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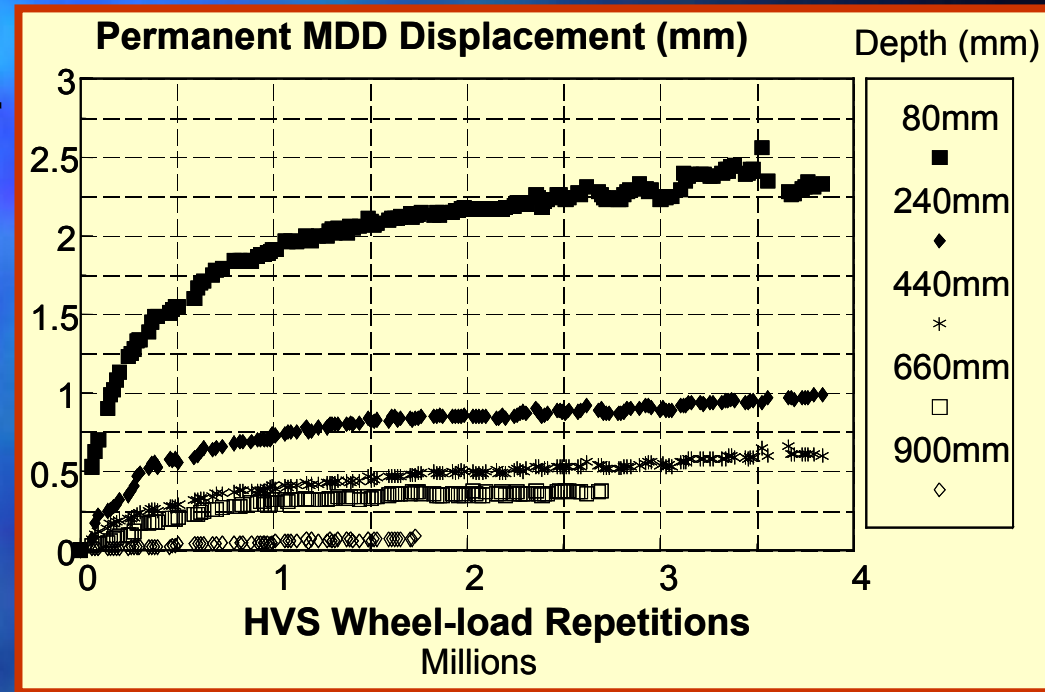
# Analysis process: Permanent MDD displacement

- Initial bedding-in
- Eventual linear rate of displacement
- Non-linear regression model

$$PD = mN + a(1 - e^{-bN})$$

a = bedding-in

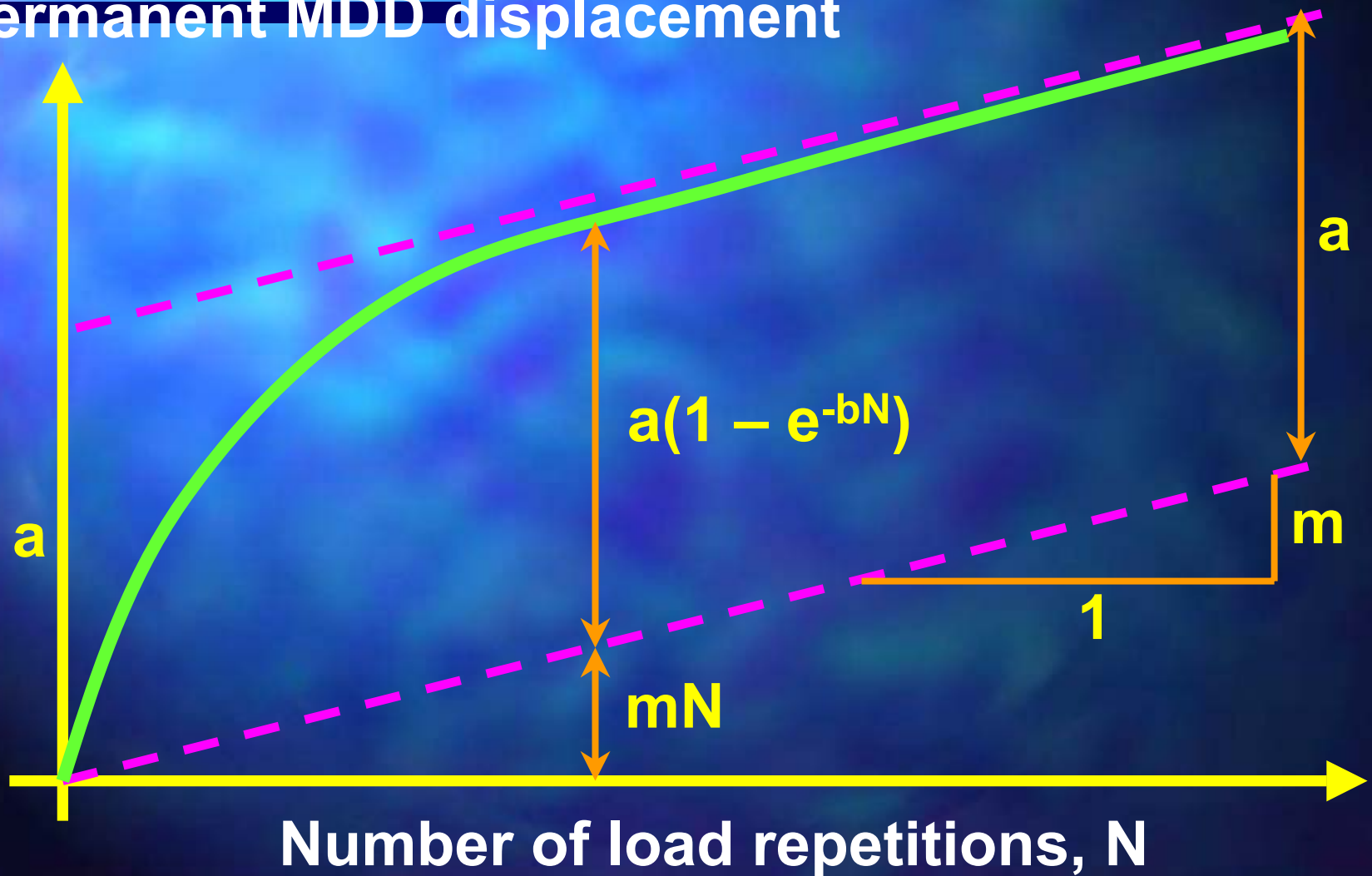
m = linear displacement  
rate



# Analysis process:

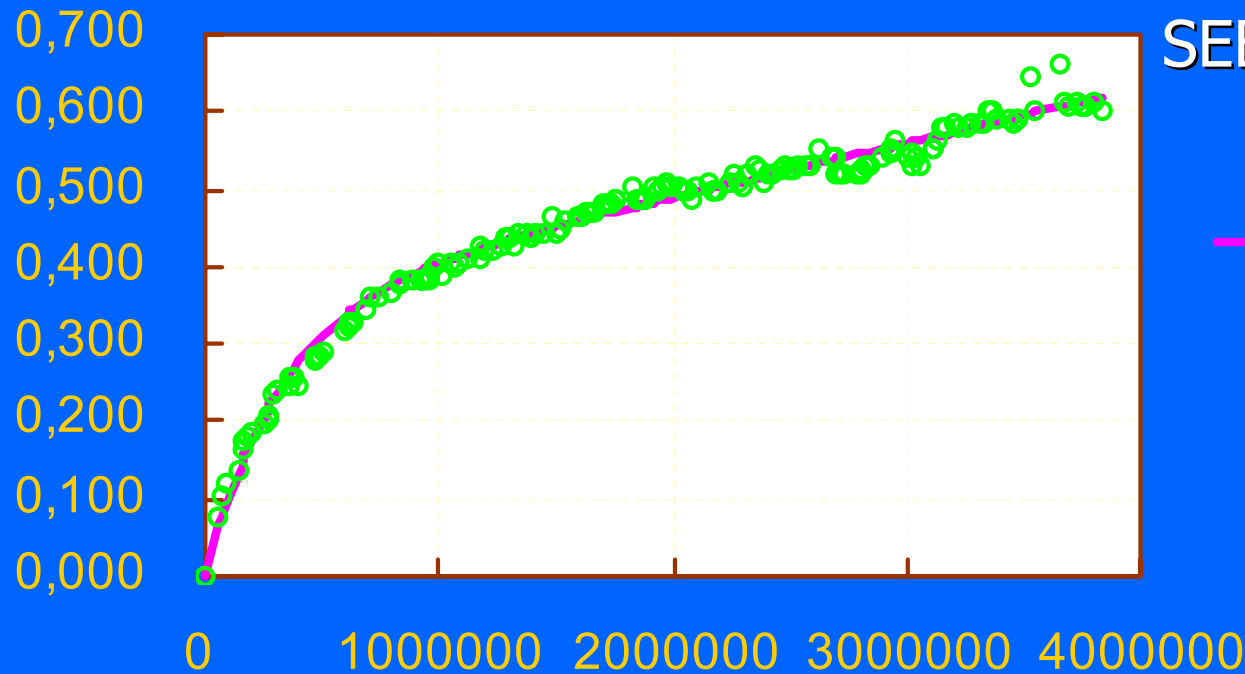
## Permanent MDD displacement

Permanent MDD displacement



# Analysis process: Permanent MDD displacement

PD (mm)

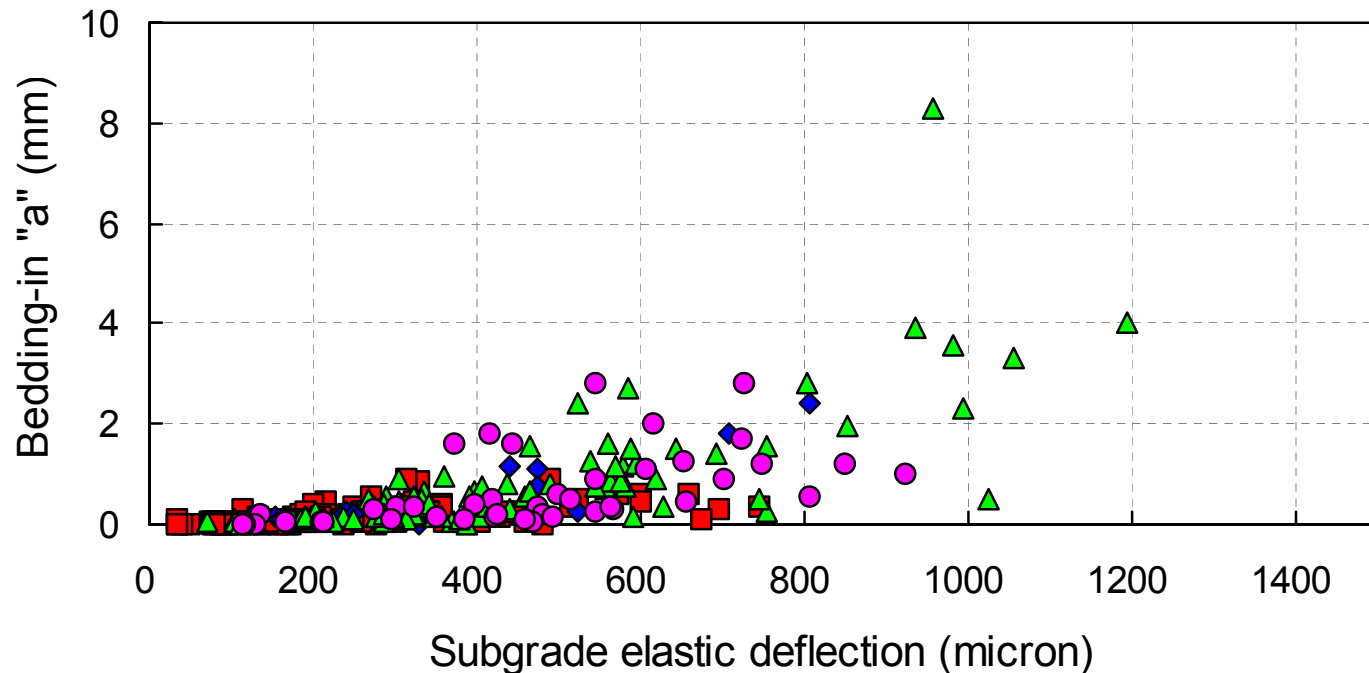


$R^2 = 0,989$

SEE = 0,014

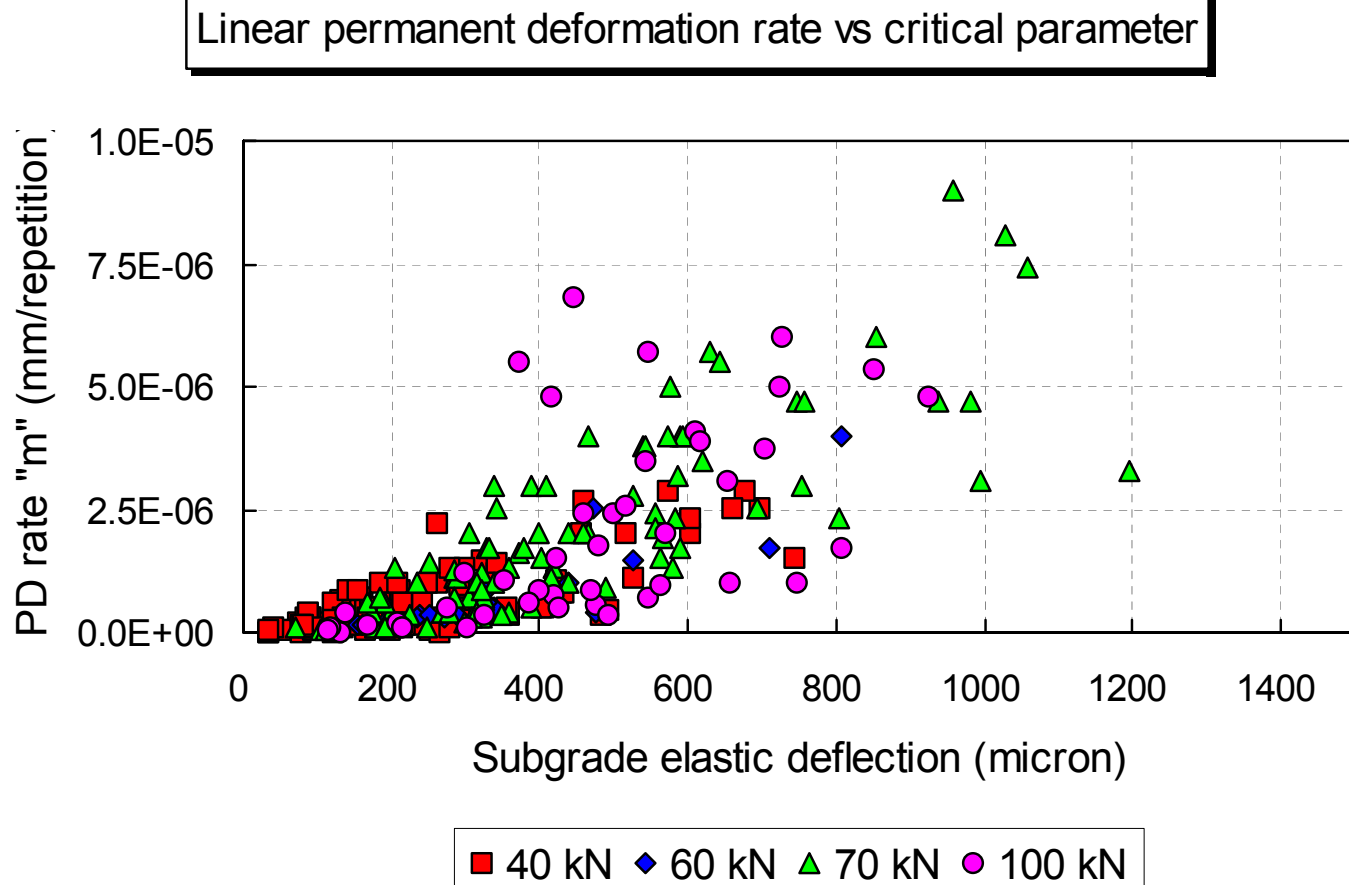
# Plastic response: Bedding-in "a"

Permanent deformation bedding-in vs critical parameter



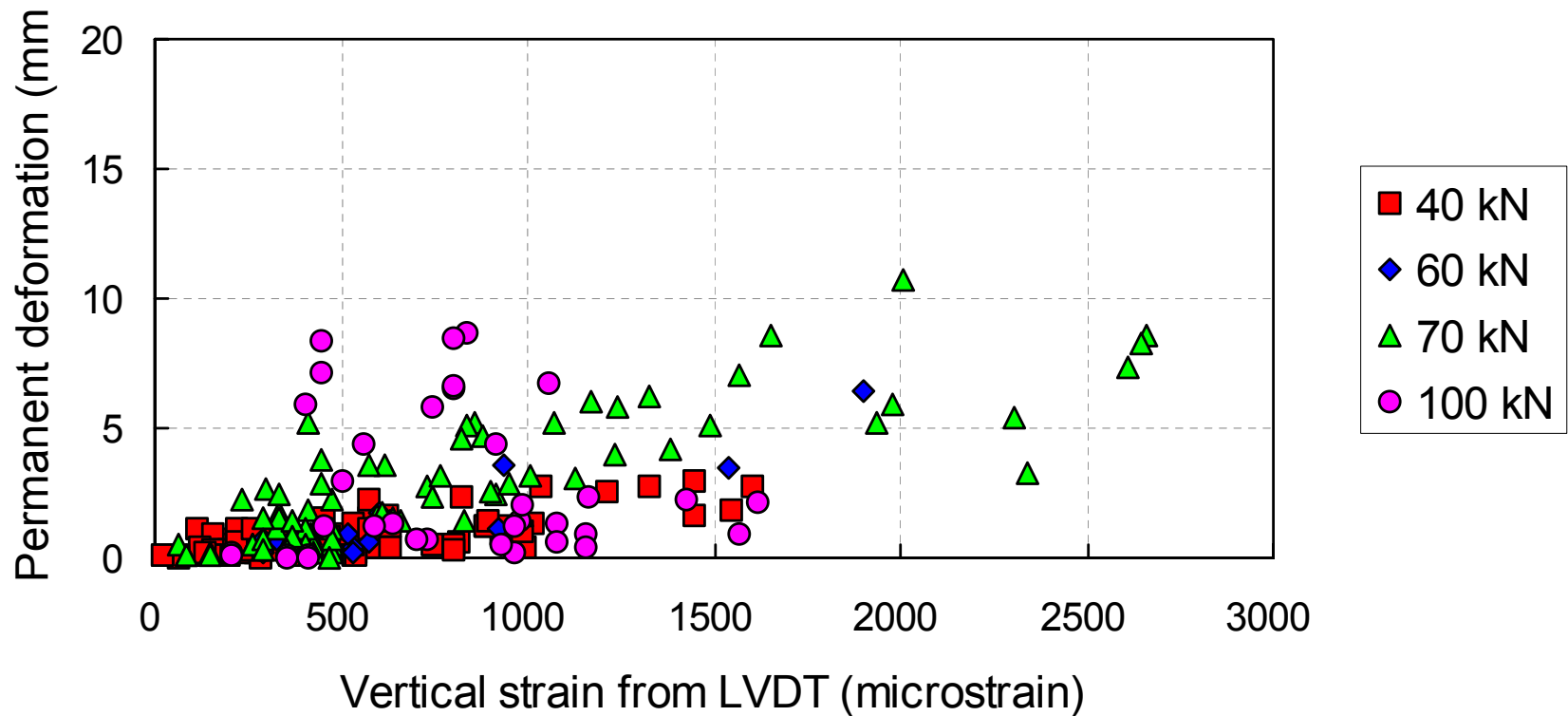
■ 40 kN ◆ 60 kN ▲ 70 kN ● 100 kN

# Plastic response: Linear deformation rate "m"



# Plastic response: Critical parameter, $\epsilon_v$

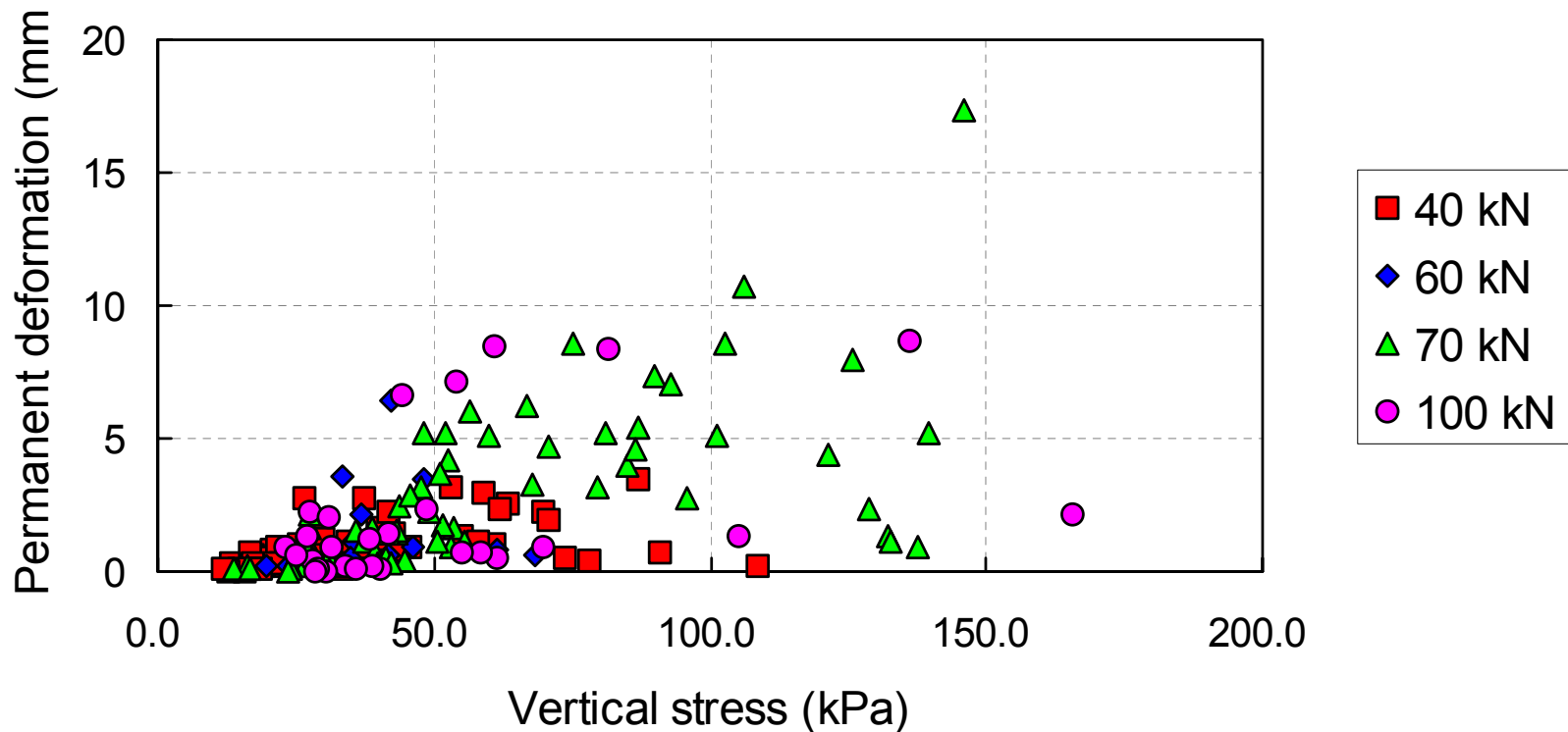
Subgrade permanent deformation at 200 000 load repetitions



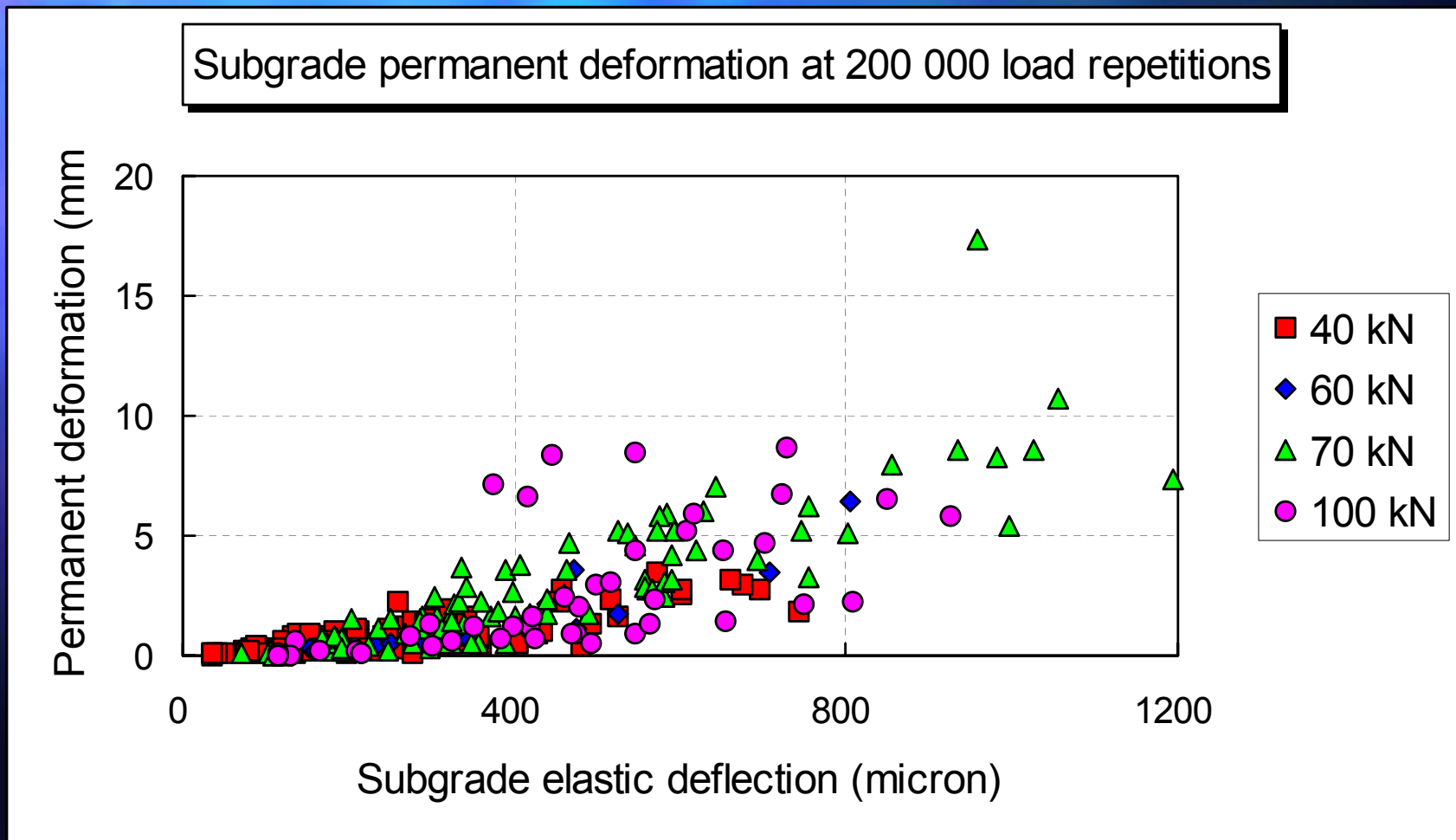
# Plastic response:

## Critical parameter, $\sigma_v$

Subgrade permanent deformation at 200 000 load repetitions



# Plastic response: Critical parameter, $\delta_s$





# Design models

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Subgrade Deformation:  
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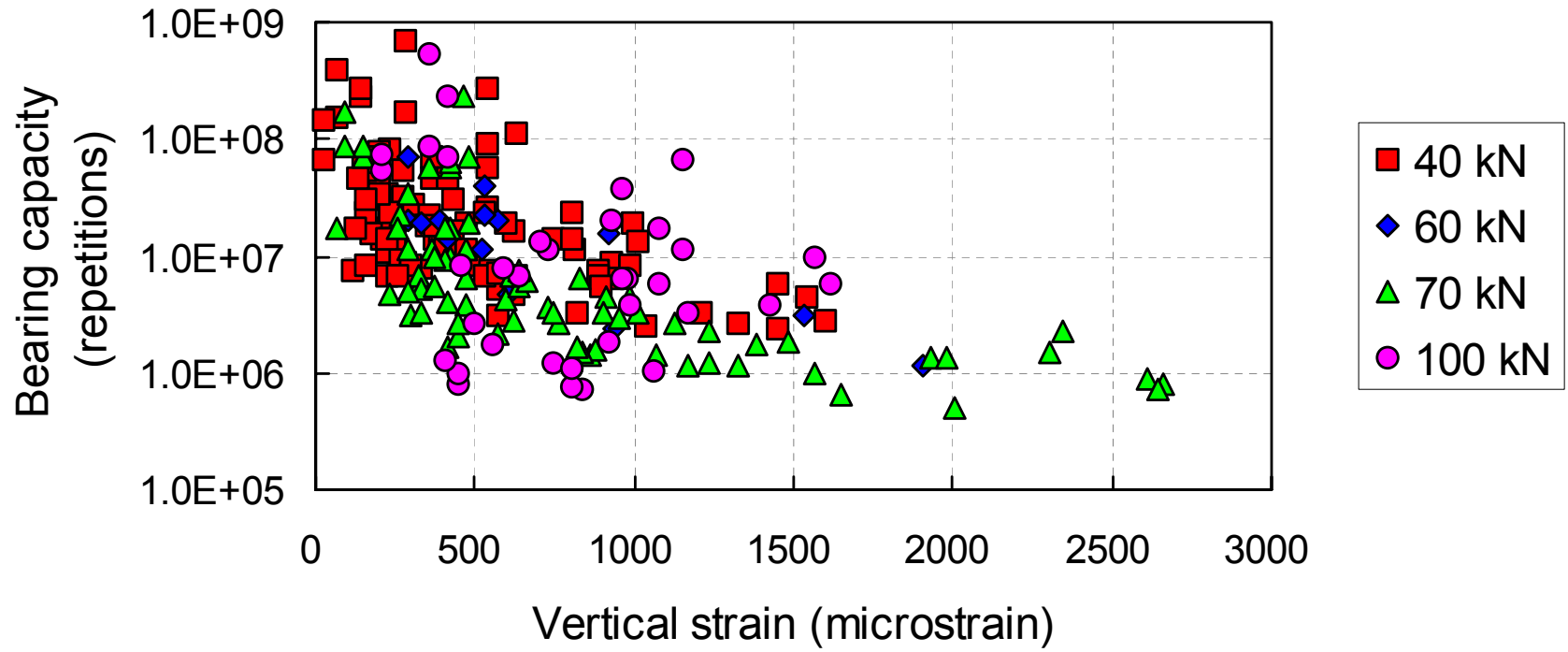
# Subgrade design transfer functions (S-N curves)

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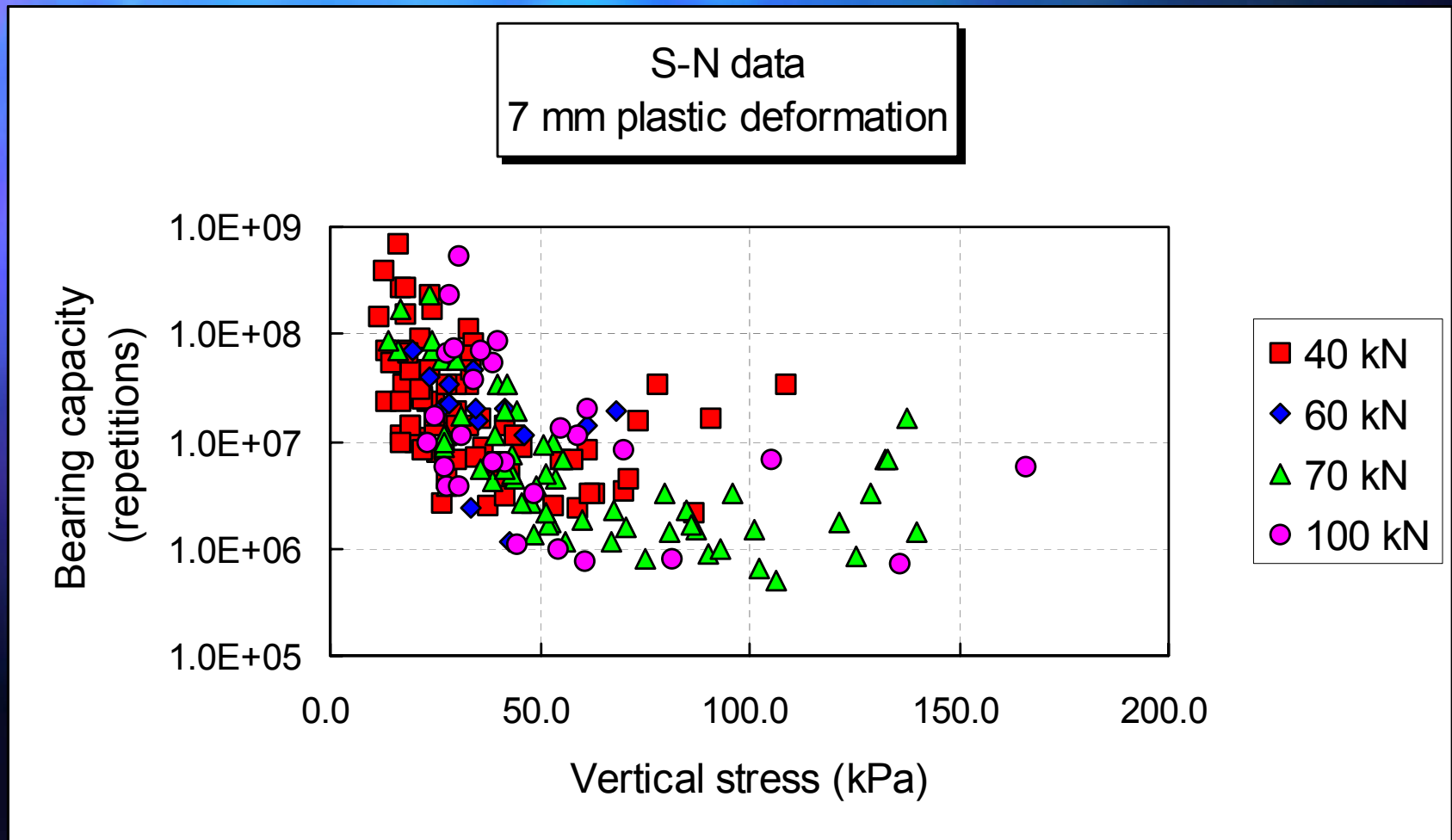
- S-N data
- S - Stress parameter
- N - Number of repetitions to reach a certain, predetermined level of subgrade deformation
- N solved from regression function for each MDD module from top of subgrade downwards
- Regression of S-N data on a log-linear scale

# Plastic response: S(vertical strain)-N data

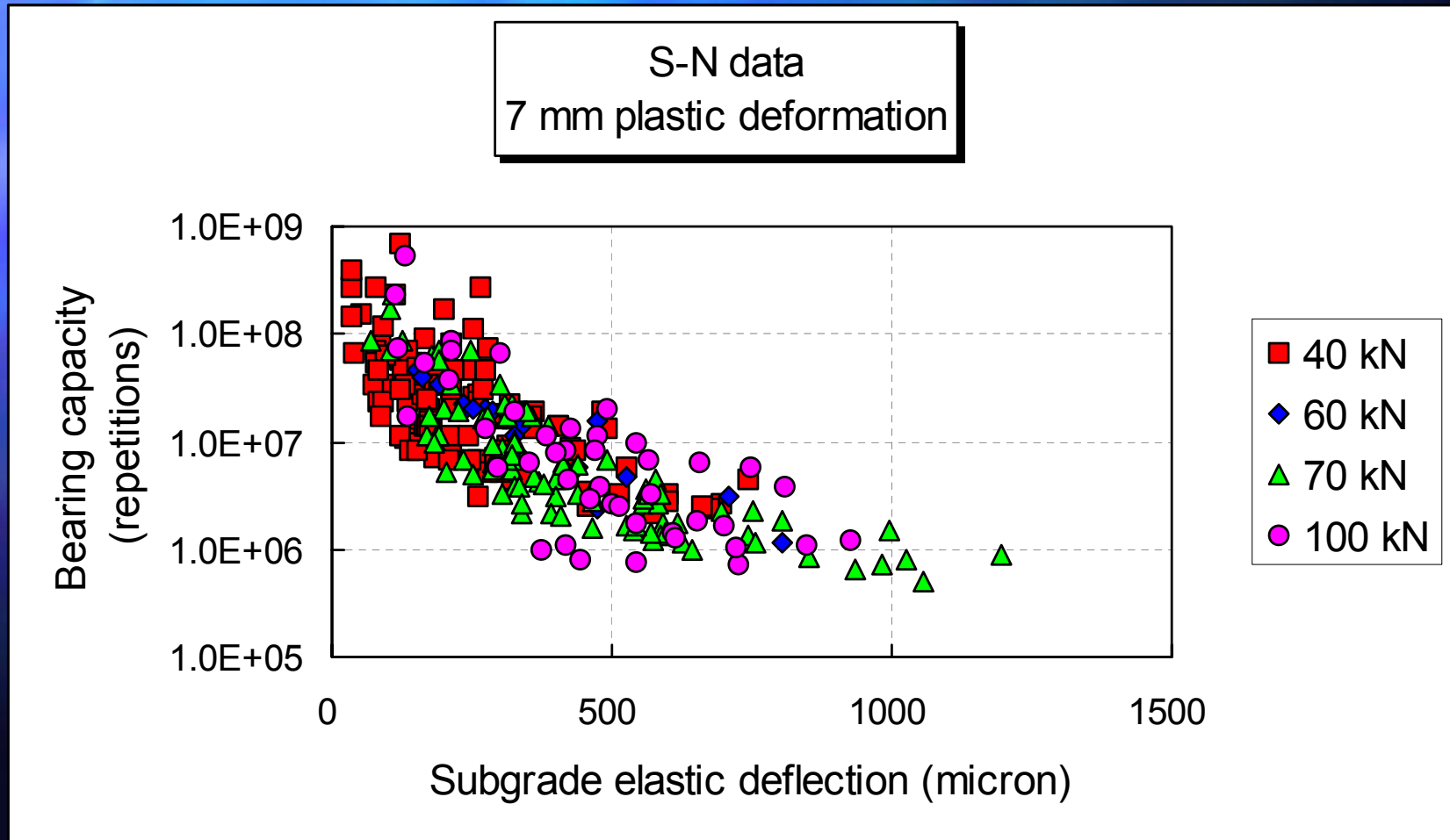
S-N data  
7 mm plastic deformation



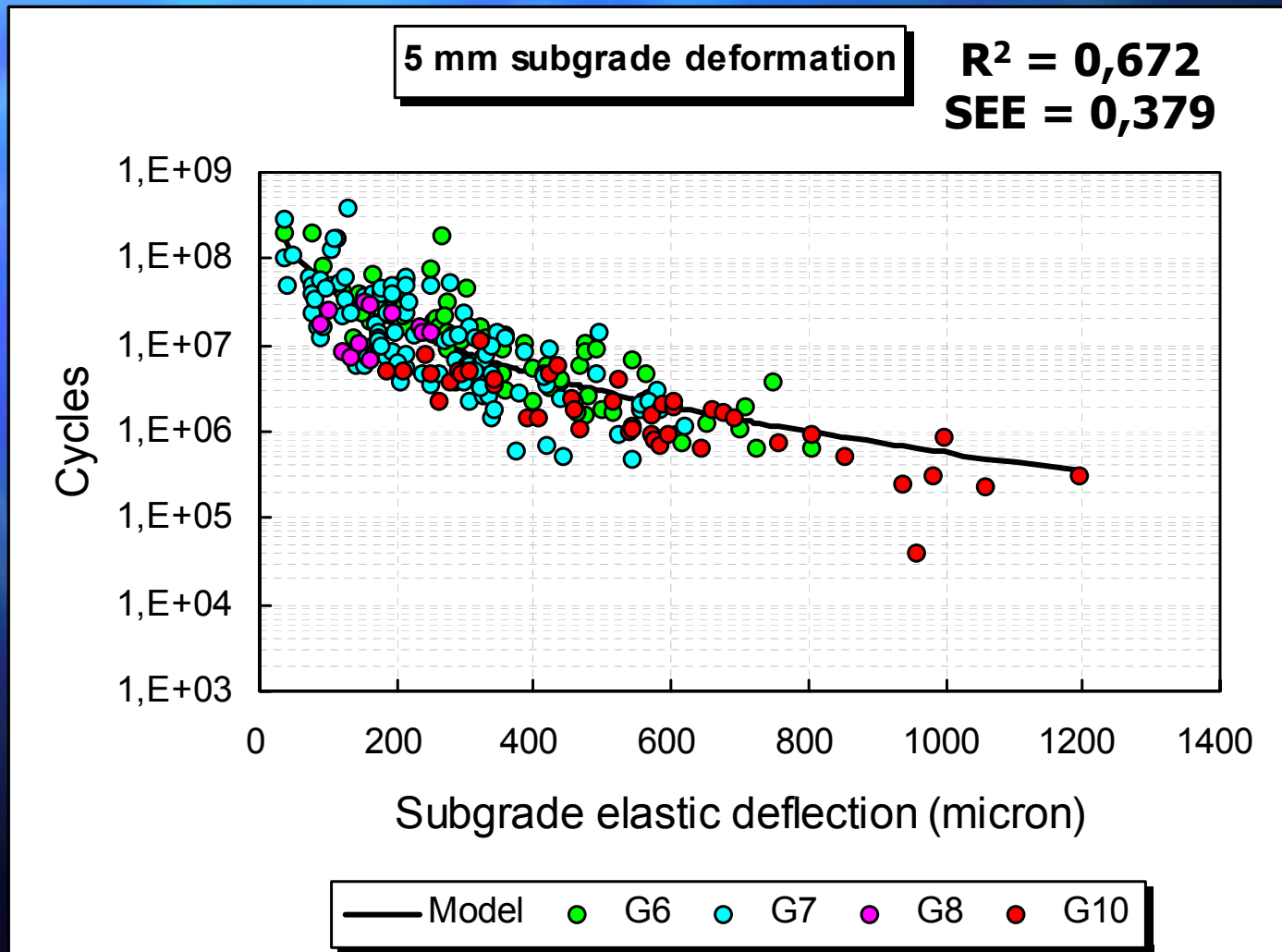
# Plastic response: S(vertical stress)-N data



# Plastic response: S(subgrade deflection)-N data

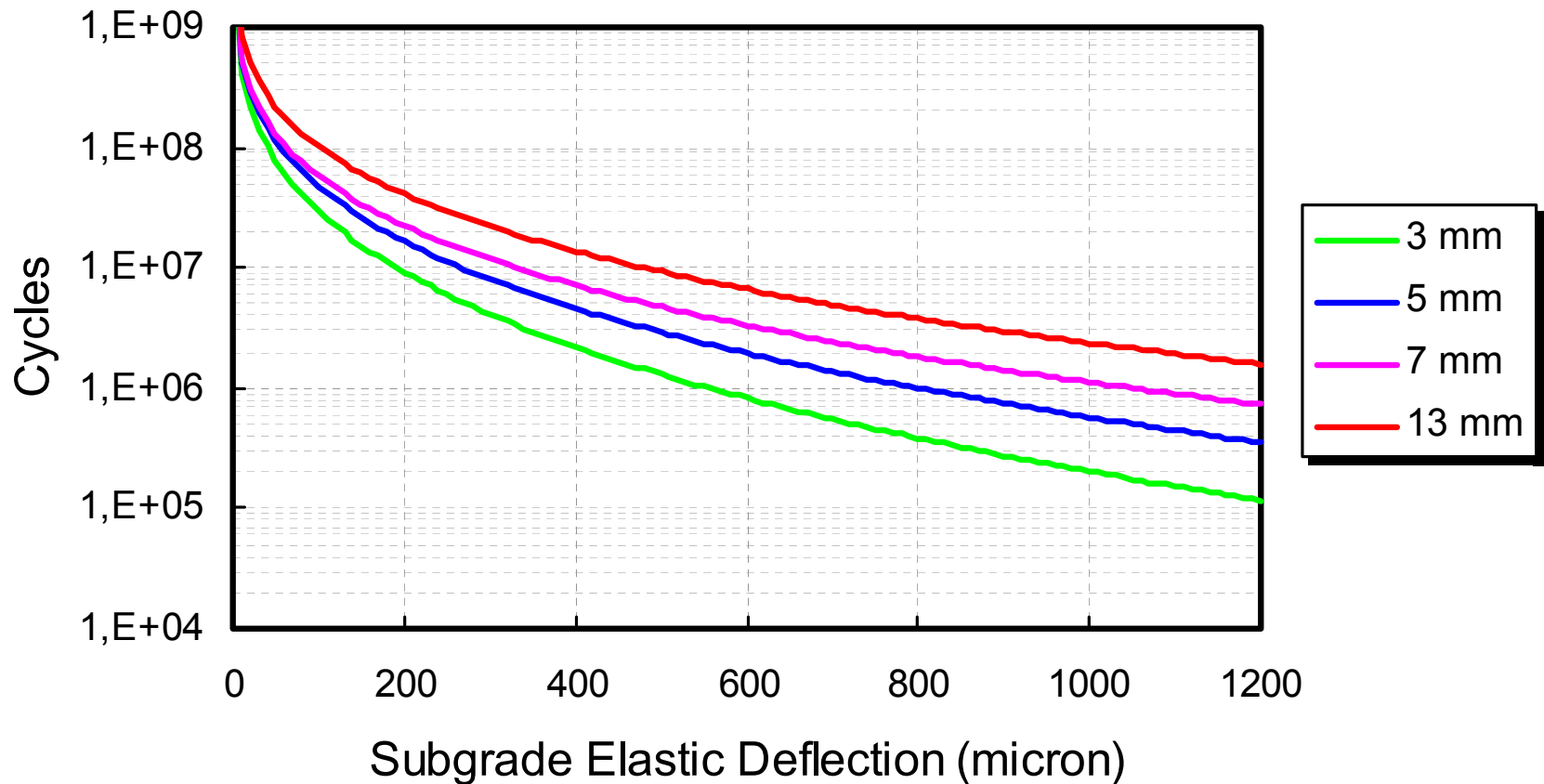


# Plastic response: S-N subgrade deformation model



# Plastic response: S-N subgrade design models

Subgrade Design Curves



# Plastic deformation model: Conclusions

- Model based on measured parameters
- Models only valid for low shear stress zone in pavement
- Simplified model of subgrade response under normal road traffic loads
  - Good enough for design purpose
- Subgrade elastic deflection yields the best S-N correlation
- Model not calibrated for field variables
  - Density
  - Degree of saturation
- Further refinements are possible



# Model refinement

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# Issues to address

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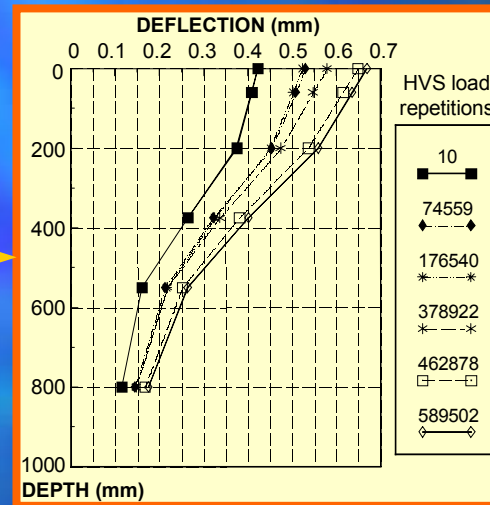
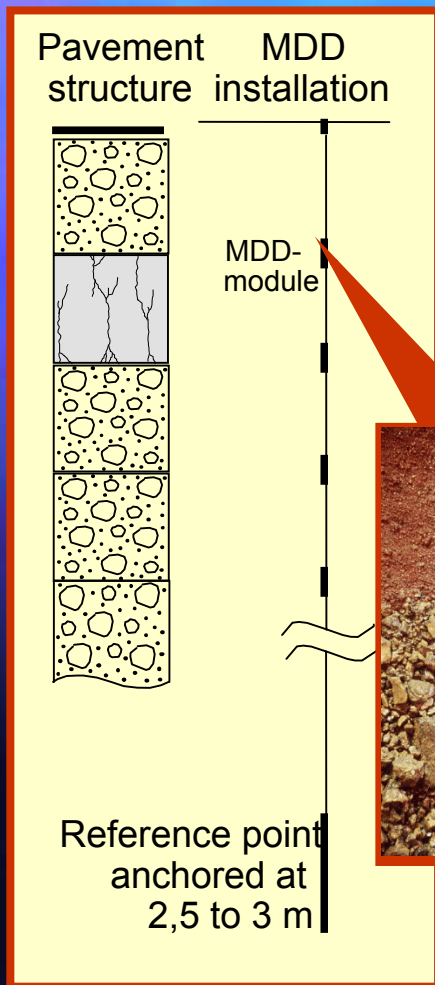
- Calibration of a continuous model
  - Recursive/incremental distress analysis
  - Pavement systems approach to rutting
- Resilient modulus models for the pavement subgrade
  - Current work based on measured parameters
  - Subgrade elastic deflection will have to be calculated in the design case

# Continuous model

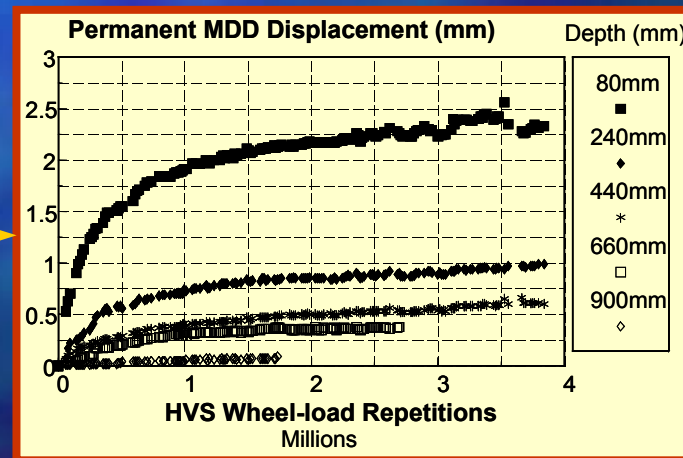
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- Applied to HVS data from Richmond Field Station, CA (CALAPT program)
- Each set of readings contains
  - Number of repetitions ( $N$ )
  - Subgrade elastic deflection ( $\delta_s$ )
  - Total subgrade plastic deformation (PD)
  - Data triplets –  $N, \delta_s, PD$

# Approach to calibration



◆  $\delta_s @ N$



◆ PD @ N

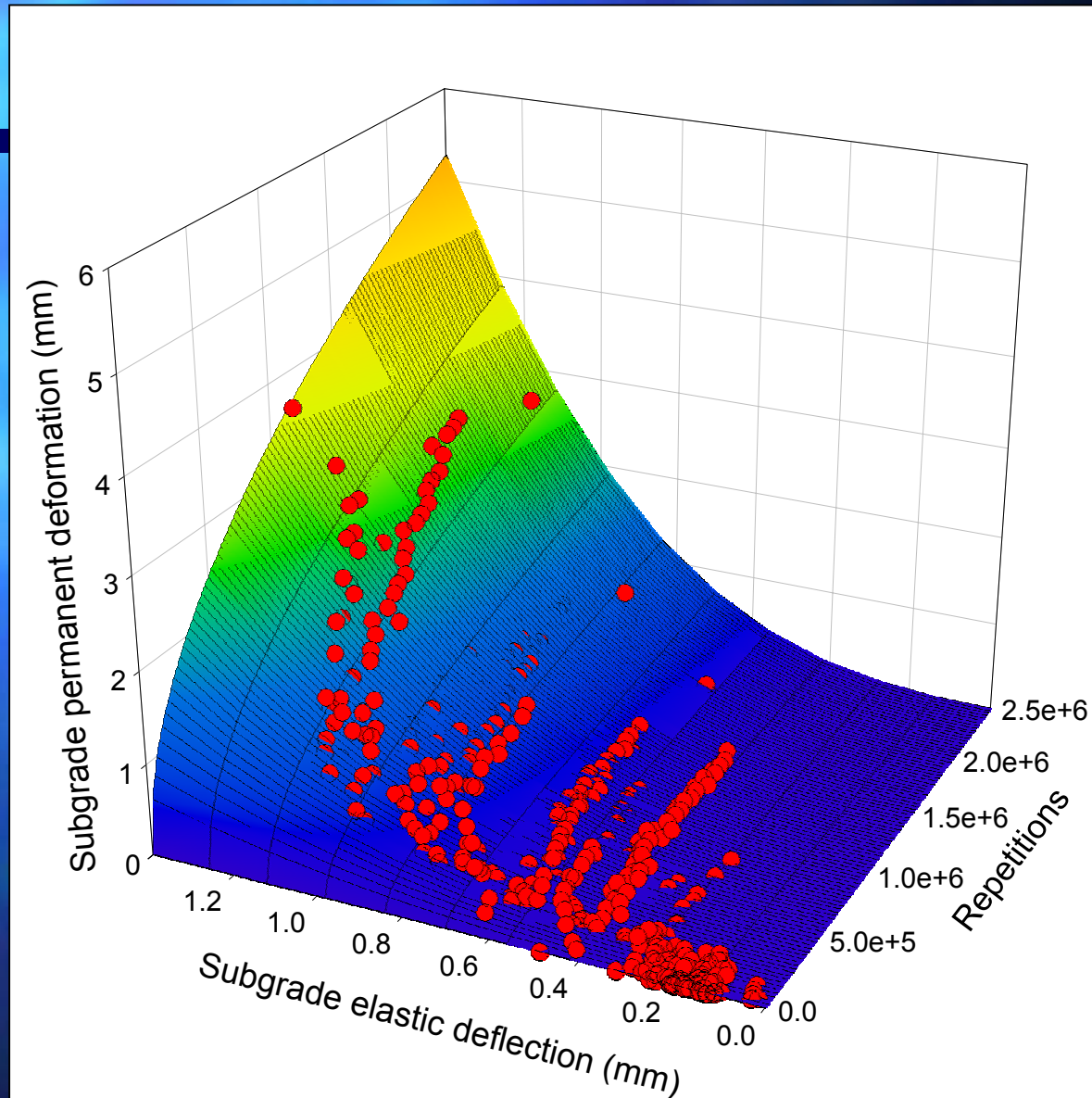
# Models fitted

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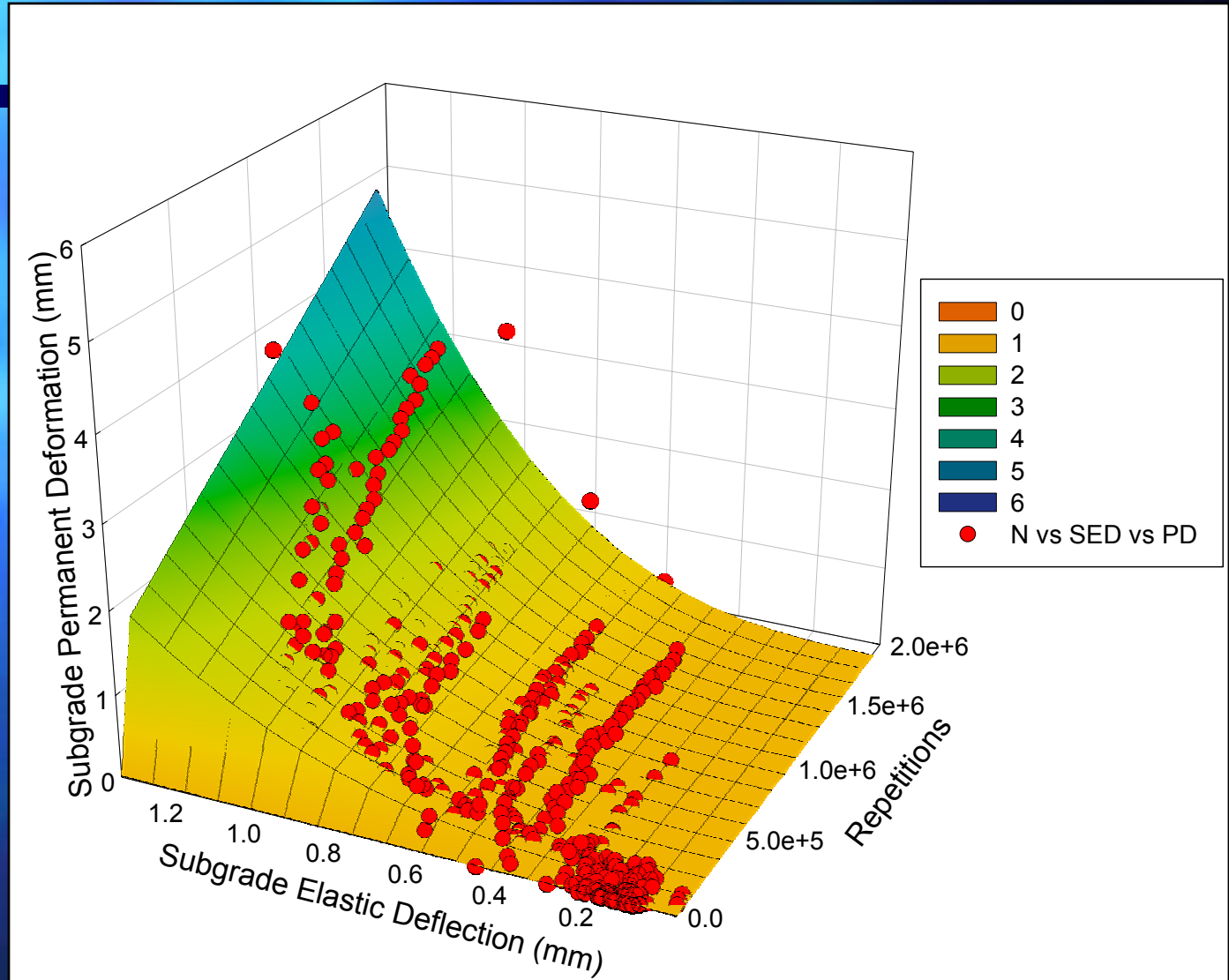
- $PD = A N^\alpha \delta_s^\beta$

- $PD = (mN+a)(1-e^{bN}) \delta_s^c$

# Continuous subgrade distress models



# Continuous subgrade distress models



# Deflection calculation in the design case

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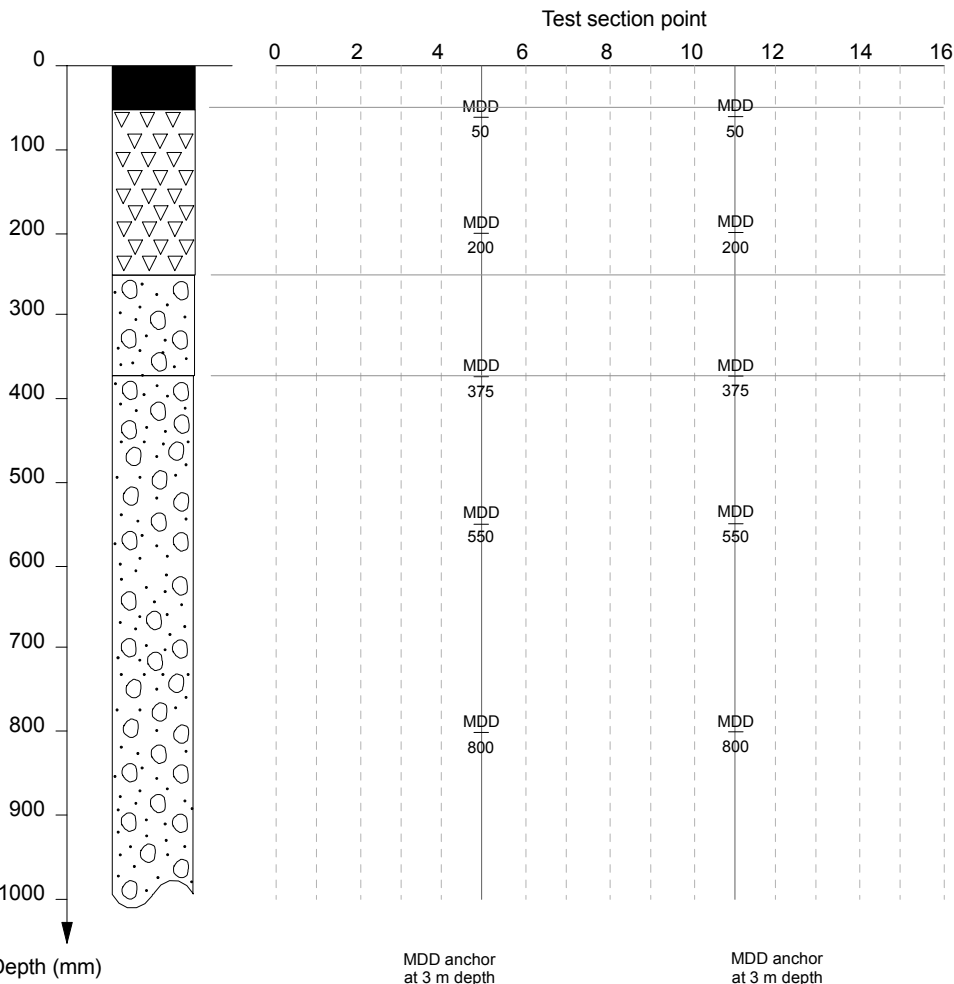
- Use MDD deflection data with
  - Top-cap MDD module
  - Two modules in subgrade
- Do MDD back-calculation
- Combine data for similar materials
- Investigate non-linearity if possible



**Pavement structure**

**Instrumentation detail**

**Pavement material information**



Layer	Type	Material properties (UCS, CBR, MDD, OMC, etc)	Field		TRH14 class
			Density (kg/cub m)	MC (%)	
0 - 50	Asphalt	New and old asphalt surfacing layers			
50 - 250	Crushed Stone	mDD = 2233, OMC = 5,5 CBR = 91 @ 98 % GM = 2,25	99,5% mDD	3,1	G2
250 - 370	Natural gravel subbase	mDD = 1908, OMC = 10,3 CBR = 48 @ 95 % GM = 2,06	87,4% mDD	12,9	G5
370 +	In-situ subgrade	Stony limestone and sand mDD = 1926 OMC = 12,1 CBR = 27 @ 93 % GM = 1,65	95,8% mDD	11,2	G6

MDD anchor at 3 m depth

MDD anchor at 3 m depth

**Load sequence detail:**

Repetitions		Test information		
From	To	Wheel load	Tyre pressure	Water added
0	604 735	40 kN	520 kPa	No
604 735	1 245 733	60 kN	690 kPa	No

**Related reports:**

[No report available](#)

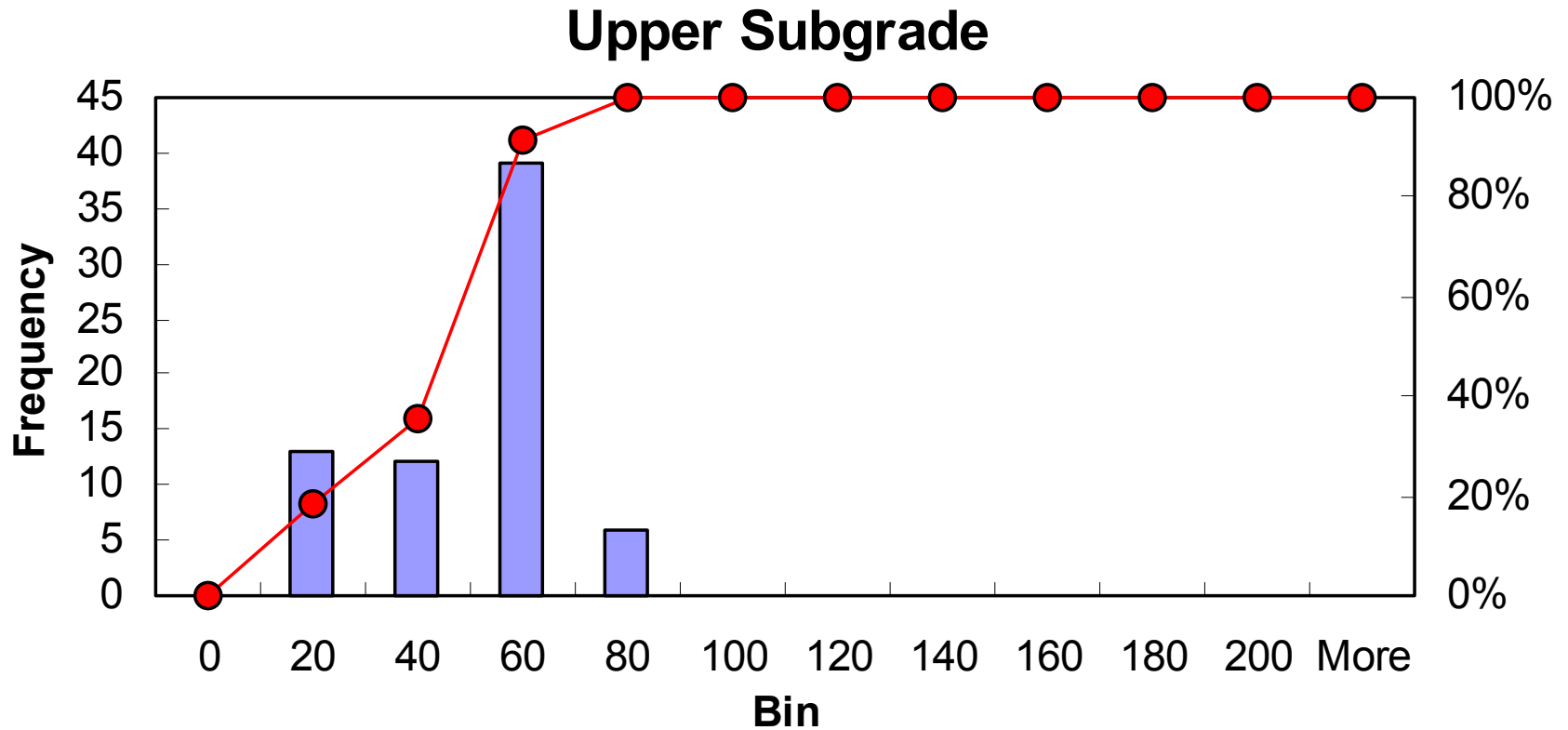
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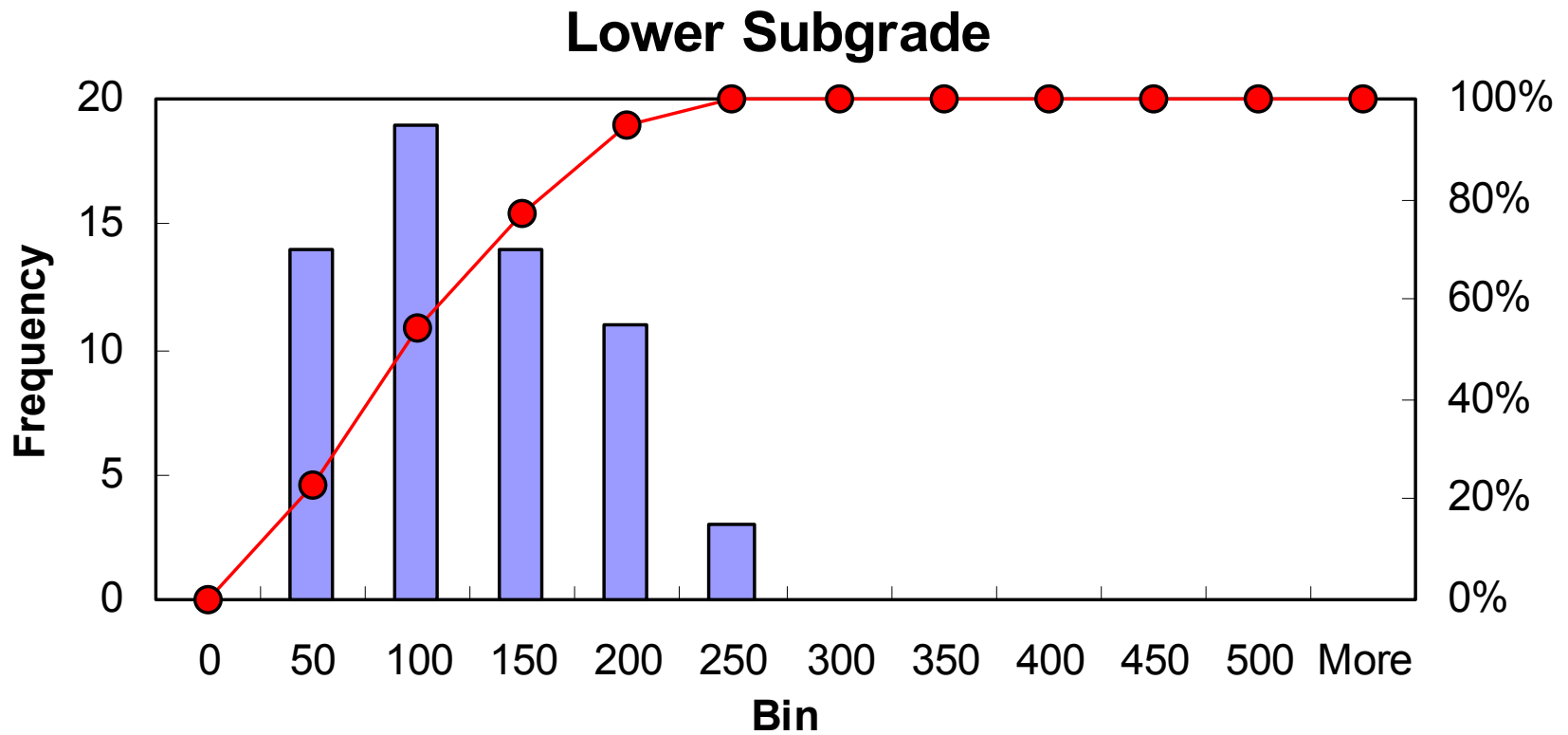
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# Upper subgrade $M_r$



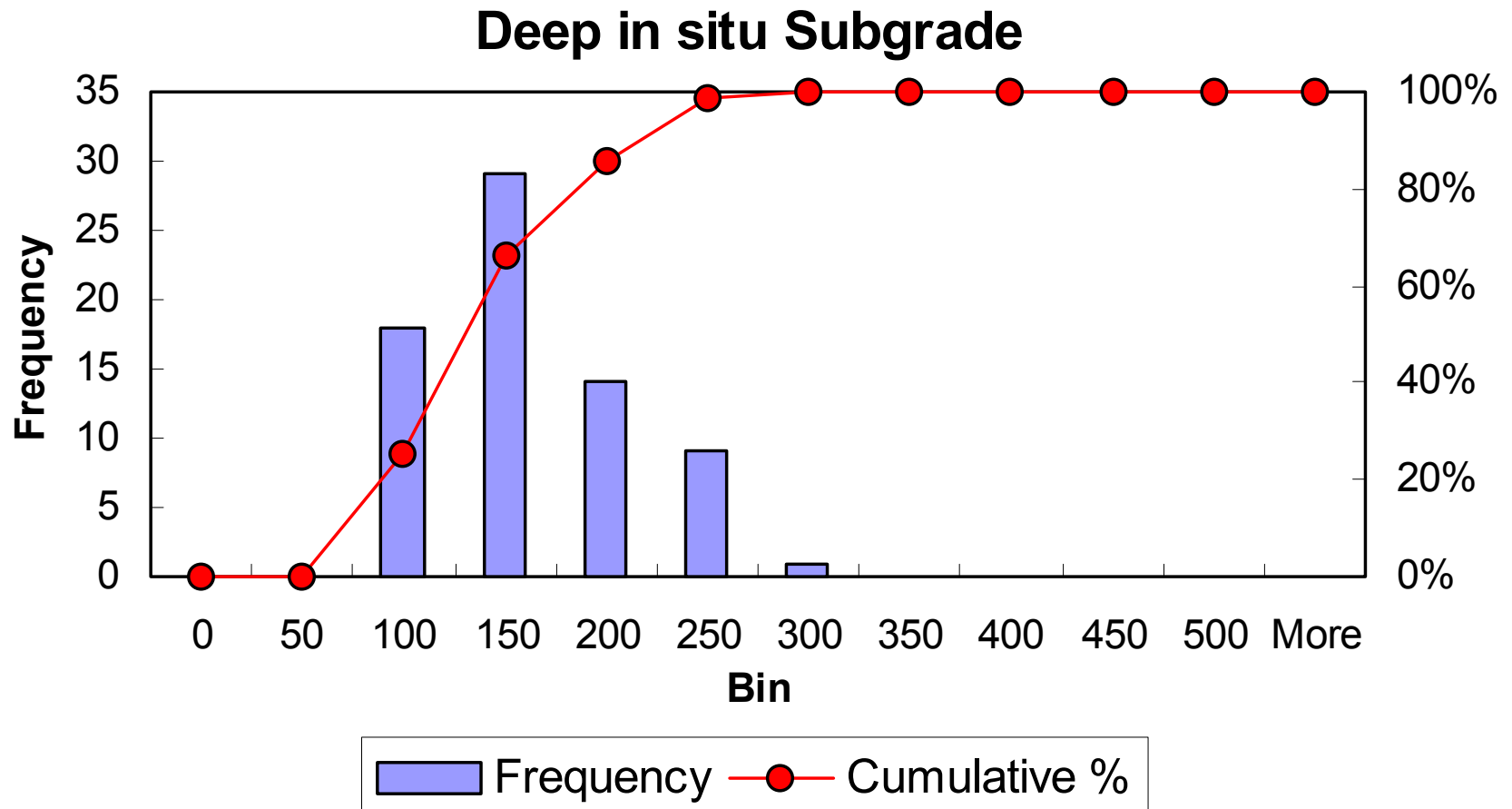
Frequency Cumulative %

# Lower subgrade $M_r$



Frequency Cumulative %

# Deep in-situ subgrade $M_r$



# To summarize

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- Best correlation was found between subgrade permanent deformation and subgrade elastic deflection
  - Subgrade elastic deflection selected as the critical parameter for subgrade design model
- Model does not explain a lot of the variation in data
  - Effect of moisture content and density excluded
  - Data not available
  - Given the amount of deformation contributed by the subgrade – no further refinement

# To summarize (continued)

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- Working on
  - Back-calculations
  - Non-linear model calibration
  - Calibration of continuous distress model for South African data